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ORIGINAL ARTICLE

Anatomical details used in the surgical reconstruction of the lacrimal canaliculus: cadaveric study

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Abstract
Purpose The purpose of this study was to investigate the proximal part of the lacrimal tract.
Methods The dissection was performed on 20 specimens of adult cadavers under an operating microscope.
Result The upper lacrimal canaliculus (ULC) and the lower lacrimal canaliculus (LLC) were opened to the lacrimal sac (LS) in three types. In Type A, the ULC and the LLC unite before opening to the LS and form the a common canaliculus (CC). In Type B, the ULC and the LLC unite at the wall of the LS and open to the LS via common hole. In Type C, however, the ULC and the LLC open to the LS separately. Type A, Type B and Type C were observed in 85%, 5% and 10% cases, respectively. Type A and Type B opened to the LS from back to front at an acute angle in 72% of the specimens, and at a right angle in 22%. The opening angles of the CC with lacrimal canaliculus; the ULC with the LS, and the LLC with the LS were realized at an acute angle.
Conclusion Crucial parameters, which have not been previously mentioned such as the opening angles of the ULC and the LLC, were investigated as they might be used during the procedure.

Keywords Lacrimal canaliculus · Common canaliculus

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Introduction

The nasolacrimal system comprises the lower lacrimal canaliculus (LLC) and the upper lacrimal canaliculus (ULC), the common canaliculus (CC), the lacrimal sac and the nasolacrimal duct [10]. The ULC and the LLC each consists of a vertical segment and a horizontal segment [9, 14, 16, 29, 30].

Obstruction of the lacrimal drainage system can lead to watery eye with blurred vision, intermittent or constant tearing (epiphora) and acute or chronic dacryocystitis. Obstruction can occur at any level along the lacrimal outflow pathway; at the punctum, canaliculus, lacrimal sac, nasolacrimal duct or nasal ostium [5, 8].

Epiphora is a common eye disorder that is caused by congenital obstruction, infection, fracture, calculus or tumour; furthermore, epiphora may be associated with scarring from trauma or injury from surgery [15, 19, 21, 28]. The ULC, the LLC and the CC are repeared by using the dacrocystorhinostomy, lacrimal stents and the dacrystoplasty techniques for the drainage of the lacrimal portion [19, 26–28]. The reported success rate of conventional external dacryocystorhinostomy is 90–95% [17, 19]. The reasons for surgical failure include incorrect identification of the lacrimal sac, failure to make an adequate osteotomy, fall back of lacrimal sac flaps and fibrosis of the bony osteotomy [19]. The most important reason of all is anatomical ignorance. Hence, the surgeons encounter perioperative difficulties like haemorrhage, tissue plane adhesions, difficult probing and false passage formation more frequently [4, 24].

Some anatomical reasons have been explained for the canalicular obstruction in patients with enlarged sac [5, 12, 16, 18, 32]. According to a view, enlargement of the lacrimal sac may change the anatomic course of the CC, and entry of the canaliculus in the sac with prominent anterior angulation may facilitate valve-like obstruction. Another view suggests that there is no CC in these cases; the canaliculi opens separately in a sinus, and a mucosal folds on the upper posterior margin of this opening. This mucosal folds like Rosenmuller valve and prevents fluid reflux from the sac in the canaliculi.

Although some researchers have devoted their anatomic findings to the lacrimal canaliculus, little attention has been given to form reliable surgical landmarks [11, 13, 20]. Most of the studies are retrospective case series. Since the surgical anatomic landmarks of the lacrimal canaliculus have not been examined in detail, individual surgical techniques are not standized, and there is a great deal of difference among the investigators in terms of the surgical procedures [3, 5]. The canalicular obstructions especially those of the LLC present some of the most difficult problems in lacrimal surgery [25]. In surgery, it is important that the anatomical orientation points be determined. The purpose of this study was to investigate some useful surgical landmarks of the CC, especially at its entry point into the lacrimal sac for external and endoscopic approaches.

Materials and methods

For this study, dissection was performed on 20 specimens of 50–75-years-old male adult cadavers from the Aegean region with no macroscopic pathologies in the orbital region. All the procedures were performed under an operating microscope (Möller Wedel Spectra) equipped with a camera and video system. The use of an operating microscope enabled us to make very clear dissections of the lacrimal drainage system. To expose the nasolacrimal duct, osteotomy was done as in dacryocystorhinostomy using chisel and rondeur meticulously under the operating microscope. During dissection, the middle nasal concha was pulled upwards and the maxillar line was determined, and the mucosa and the periosteum were cut over this line. The lacrimal bone was taken out backwards from the lacrimomaxillary suture. The frontal process of the maxilla was taken out from the lacrimal margin to the anterior lacrimal crest. The nasolacrimalis duct and the lacrimal sac on the lateral were exposed. The lacrimal sac and the nasolacrimal duct were vertically cut from the medial wall. After exposing the lacrimal sac, the nasolacrimal duct was slit slightly towards the lower end using a razor blade to expose the inner surface. The lacrimal sac was also slit towards the upper end to expose the inside. The inner surfaces of the ULC, the LLC and the CC were exposed after inserting a metal probe from the upper and lower lacrimal puncti towards the lacrimal sac (Fig. 1a–f).

Electronic digital calipers were used in measurements. In the photographs, 1-mm marked ruler was used. Mucosal structure and the opening hole of the lacrimal canaliculus to the lacrimal sac were analyzed (Fig. 2). The following observations and measurements have been made:

- whether the lacrimal canaliculus open to the lacrimal sac separately or together;
- the distance between the opening hole of the CC and the upper point of the fornix of the lacrimal sac;
- the distance between the opening hole of the ULC and the upper point of the fornix of the lacrimal sac;
- the distance between the opening hole of the LLC and the upper point of the fornix of the lacrimal sac;
- the distance between the opening hole of the CC and the (junction of the sac and canaliculi) lower end of the lacrimal sac;
- the distance between the opening hole of the ULC and the (junction of the sac and canaliculi) lower end of the lacrimal sac;
- the distance between the opening hole of the LLC and the (junction of the sac and canaliculi at the lower) lower end of the lacrimal sac.

In order to detect whether there are statistically meaningful differences between the measurements on the right and left sides of the specimens, student's *t* test was made for two specimens matched. The "*P*" values, which were lower than 0.05, were considered statistically meaningful.

Results

The ULC was smaller and shorter than the LLC. It ascended and bended at an approximately acute angle, and passed medially and downwards to reach the nasolacrimal sac. The LLC first descended and turned almost horizontally to the sac. The lacrimal sac was bounded by the anterior lacrimal crest of the maxilla in the front and by the posterior lacrimal crest of the lacrimal bone behind.

Measurements, which belong to the CC, the lacrimal sac, the ULC and the LLC, were shown in Table 1. The ULC and the LLC opened to the lacrimal sac in three different types (Fig. 3). In Type A, the ULC and the LLC unite before opening to the lacrimal sac and form the CC. In Type B, the ULC and the LLC unite at the wall of the lacrimal sac and open to the lacrimal sac via a common hole. In Type C specimens, a CC or common opening was absent, and the ULC and the LLC drained separately into the lacrimal sac. The frequency of Type A was 85% (Fig. 4 a–f), the frequency of Type B was 5% (Fig. 5a, b) and that of Type C was 10% (Fig. 5c, d) (Table 2).

The opening frequency of Type A to the diverticulum was 52.94% of specimens (Fig. 4a–c). The opening frequency of Type A to the lacrimal sac was 47.05% of specimens (Fig. 4d–f). In four of the specimens belonging

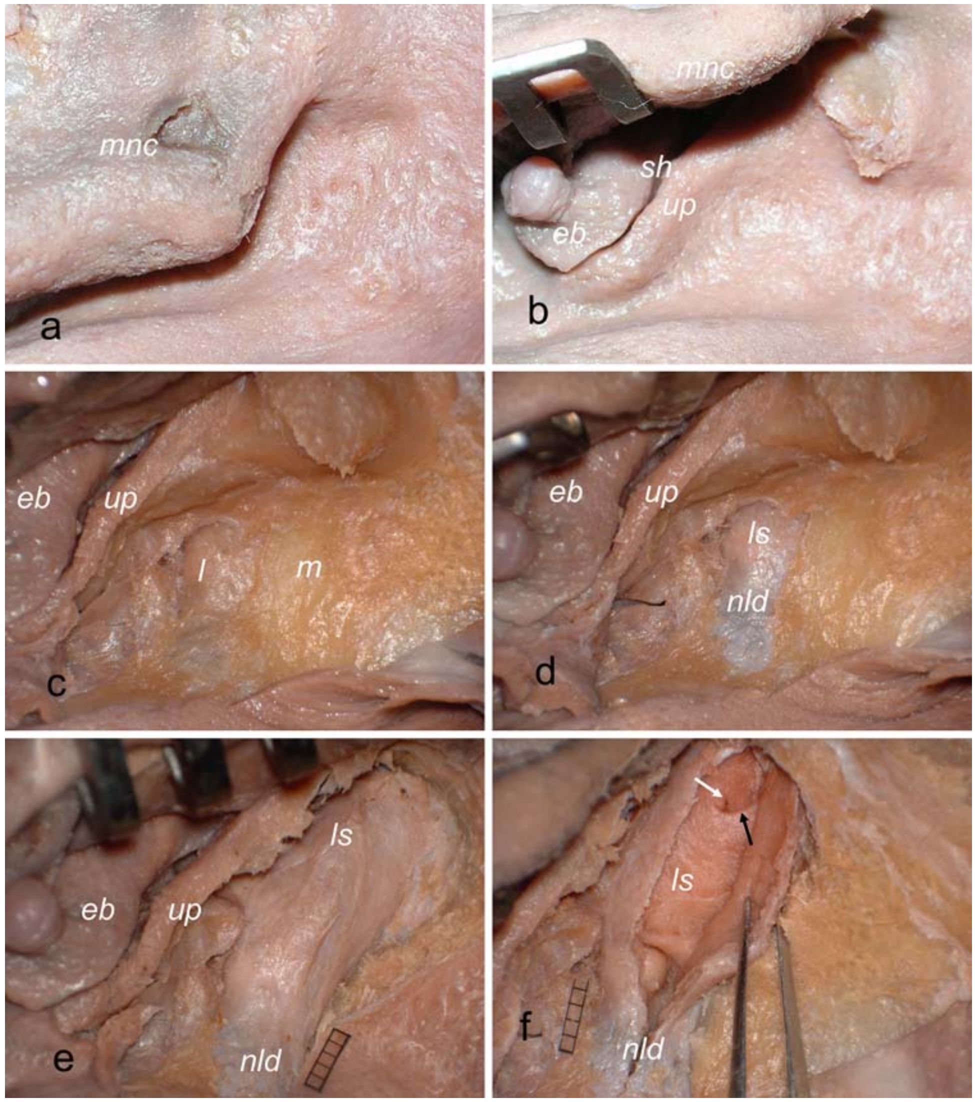

Fig. 1 **a** Nasal cavity lateral wall (*left side*). **b** Middle concha was moved upwards, the view of the middle meatus. **c** The mucosa in the front of the uncinate process was lifted. The bony structure that formed the nasolacrimal canal was revealed. **d** The lacrimal sac and the nasolacrimal duct were seen when the lacrimal bone was lifted. **e** The bony structures, which belonged to the frontal process of the maxilla and the lacrimal bone in the middle of the lacrimal sac and the nasolacrimal duct, were taken out. **f** The lacrimal sac and the nasolacrimal duct were cut along the long axis, the opening holes of the lacrimal canaliculus to the lacrimal sac and the mucosal structure were analyzed. *mnc* the middle nasal concha, *eb* the ethmoidal bulla, *sh* the semilunar hiatus, *up* the uncinate process, *l* the lacrimal bone, *m* the frontal process of the maxilla, *ls* the lacrimal sac, *nld* the nasolacrimal duct

to this group, swelling was observed in the posterior of the opening hole (Fig. 6a). In one of the specimens, swelling was detected around the hole (Fig. 4e). The opening details of the lacrimal canaliculus to the lacrimal sac as Type B and Type C were projected in Fig. 5a–e. The opening types of the CC to the lacrimal sac were detailed in Fig. 6a–f.

While Type A and Type B opened to the lacrimal sac from back to front at an acute angle in 72% of the specimens and at a right angle in 22%, in 6% of the specimens, the CC opened a little from front to back (Table 3). The ULC opened to the lacrimal sac downwards at a right angle in 50%, and swelling was observed at the upper edge of the opening hole. With 50% frequency, they opened from back to front. While the LLC opened from back to front in 100% of the specimens, swelling was detected at the back edge of the opening hole of one.

Discussion

Tears from the lacrimal gland in the orbit are propelled to the lacrimal lake in the inferomedial orbit by blinking, muscular contraction and capillary action [6, 22]. Tears enter the upper and lower puncta on the posterior edge of the medial margin of the eyelid and move through the ULC and the LLC to the CC [15, 16, 31]. The horizontal part of the ULC and the LLC converge to form a single CC, up to 3–5 mm long, which opens into the posterolateral wall of the lacrimal sac. The lacrimal sac is located in the lacrimal fossa, a depression in the inferomedial preseptal orbit was located between the anterior and posterior lacrimal crests [29, 30]. The lacrimal sac consists of an upper, more bulbous portion and a lower, more tubular portion [11, 14]. The dome of the sac, which extends above the medial canthal tendon, is covered by tough fibres.

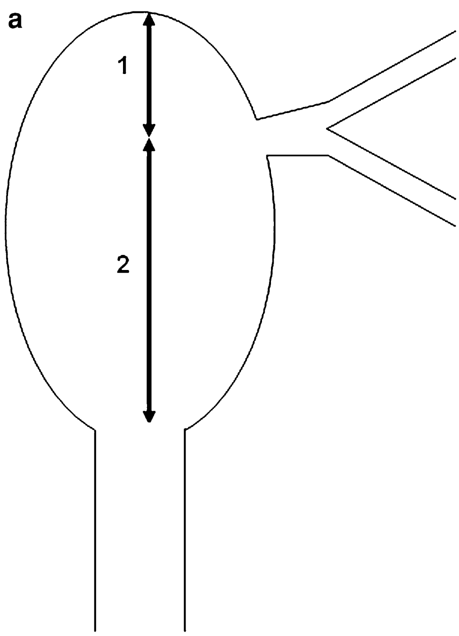

Fig. 2 **a** Some distances of the specimens of the lacrimal canaliculus open to the lacrimal sac together. *1* Distance opening hole of the common canaliculus (CC) and the upper point of the lacrimal sac. *2* The distance between the opening hole of the CC and the (junction of the sac and canaliculi) lower end of the lacrimal sac. **b** Some distances of the specimens of the lacrimal canaliculus open to the lacrimal sac separately. *1* The distance between the opening hole of the ULC and the upper point of the fornix of the lacrimal sac. *2* The distance between the opening hole of the ULC and the (junction of the sac and canaliculi) lower end of the lacrimal sac. *3* The distance between the opening hole of the LLC and the upper point of the fornix of the lacrimal sac. *4* The distance between the opening hole of the LLC and the (junction of the sac and canaliculi at the lower) lower end of the lacrimal sac

Table 1 Distances between the opening hole of the common canaliculus (CC) into lacrimal sac and the important landmarks around it (mm)

Distances	Mean ± SDev (min–max)
CC and fornix of lacrimal sac	2.79 ± 1.02 (0.8–4.9)
Upper lacrimal canaliculus and fornix of lacrimal sac	1.93 ± 0.25 (1.75–2.1)
Lower lacrimal canaliculus and fornix of lacrimal sac	2.55 ± 1.06 (1.8–3.3)
Common canaliculus and lower end of lacrimal sac	8.56 ± 1.66 (6.3–12.88)
Upper lacrimal canaliculus and lower end of the lacrimal sac	13.17 ± 0.80 (12.6–13.73)
Lower lacrimal canaliculus and lower end of the lacrimal sac	11.95 ± 0.08 (11.89–12.0)

In textbooks related to lacrimal anatomy and surgery, it is stated that in approximately 90% of the cases, the canaliculi combine to form a single CC that enters the lateral wall of the tear sac (Table 2) [6, 10, 14, 29, 31]. In only 2.0% of the specimens, the ULC and the LLC enter the lacrimal sac separately, and in 3.8%, the canaliculi united at the wall of the sac to form a common opening.

The natural axes of the canaliculi can be significantly distorted during probing [31]. More recent studies suggest that the CC consistently bends from a posterior to an anterior direction behind the medial canthal tendon before entering the lacrimal sac at an acute angle [31]. These researchers claim that the entry angle of the CC into the sac may explain the lack of reflux in some pathological conditions associated with an enlarged sac. Enlargement of the sac may result in narrowing of the acute angle between the CC and the sac. Tucker et al. claim that the acute angulation of the CC as it enters the sac may explain valve-type canalicular obstruction [29].

Hurwitz [9] concluded that the canaliculi might enter separately into the sac due to false passaging of one or both canaliculi during probing. It has been thought that sac retention in nasolacrimal duct obstruction, as observed in lacrimal sac mucocele and congenital dacrocystocele, occurred in patients without a CC [1, 19, 24, 31, 32]. Hurwitz [9] suggested that the lateral expansion of the sac tends to kink the CC, so that the canaliculus becomes S-shaped, thus preventing a reduction in the sac. The result of Tucker's team study suggests that kinking of the CC due to the compression of the dilated sac may explain sac enlargement better. The absence of the CC has been considered an important variant that can affect the results of some surgical procedures [29].

Tucker et al. [29] concluded that the CC's proceeding from outside to inside and from posterior to anterior direction and entering the lacrimal sac at an acute angle has a

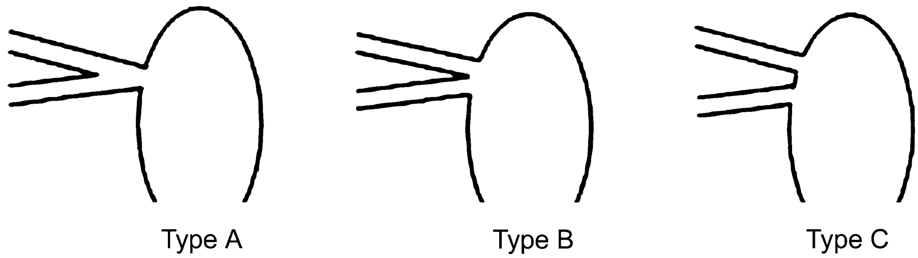

Fig. 3 Opening types of the lacrimal canaliculus to the lacrimal sac

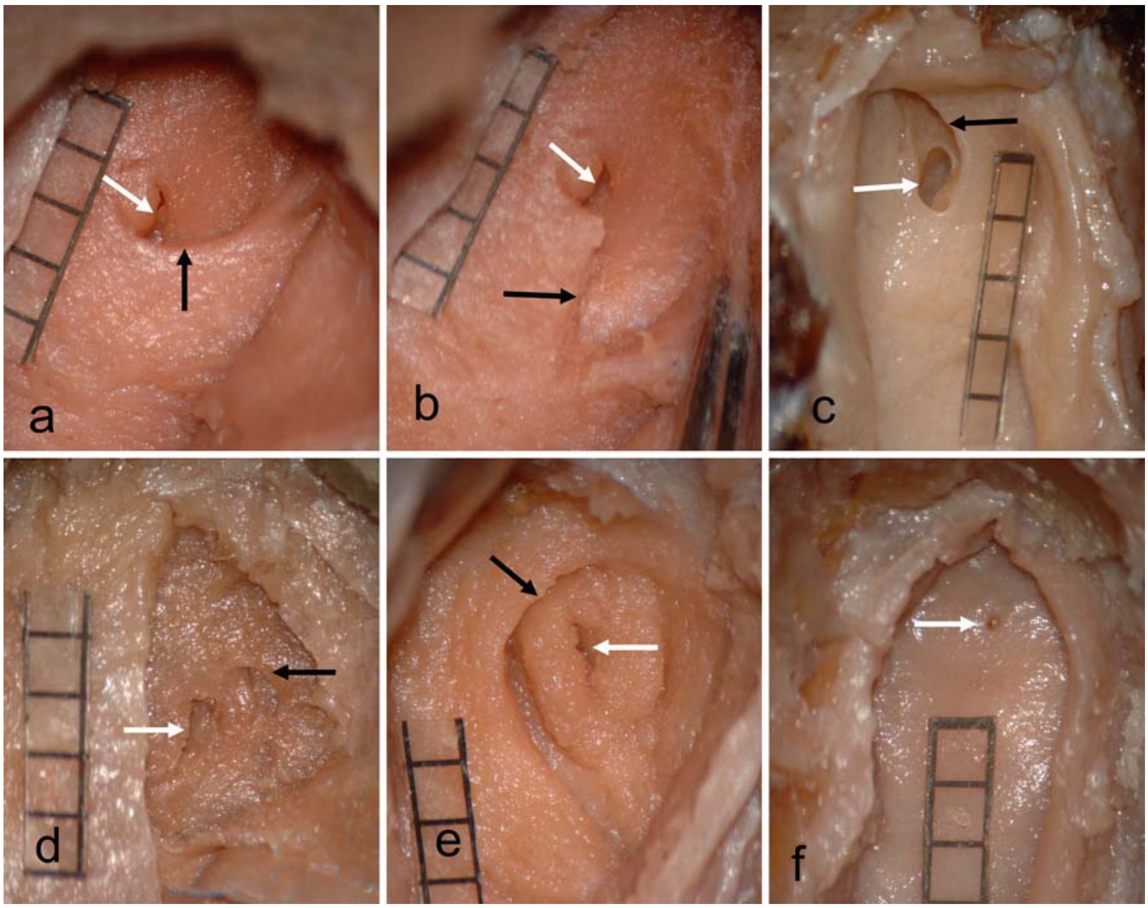

Fig. 4 Opening of the lacrimal canaliculus to the lacrimal sac as Type A. **a** Diverticulum was present at the bottom part of the opening hole of the common canaliculus. **b** Diverticulum was opened. **c** Diverticulum was present at the back and upper part of the opening hole of common canaliculus. **d** Small diverticulum was present at the front-upper part of the common canaliculus. **e** Swelling was present around the opening hole of the common canaliculus and there was diverticulum at the back part. **f** The opening hole of the common canaliculus was very small. *White arrow*: the common canaliculus, *black arrow*: diverticulum

functional significance. This study group claimed that the reason for the lack of reflux in some pathological conditions together with an enlarged lacrimal sac is the entry angle of the CC into the lacrimal sac. As the size of the lacrimal sac increases, its expansion is limited medially and posteriorly by the fornix of the lacrimal sac; and therefore, the lacrimal sac expands laterally and anteriorly. The lateral expansion may cause a kinking of the CC and this may functionally block the junction of the CC and the lacrimal sac. It is important to keep this information in mind while probing. This configuration may function like a valve [29]. During dacryosystorhinostomy, when the lacrimal sac was decompressed, it can be easily cannulated. Second, no histological evidence was found regarding a real valve at the joint of the lacrimal canaliculus and the lacrimal sac. Finally, during dacryosystorhinostomy, the inner opening of the CC in the lacrimal sac was carefully examined and the valve structure was not observed [5, 7, 8]. Former anatomists, including Rosenmuller, could not display anything else except the irregular kinkings at the joint of the CC and the lacrimal sac [12].

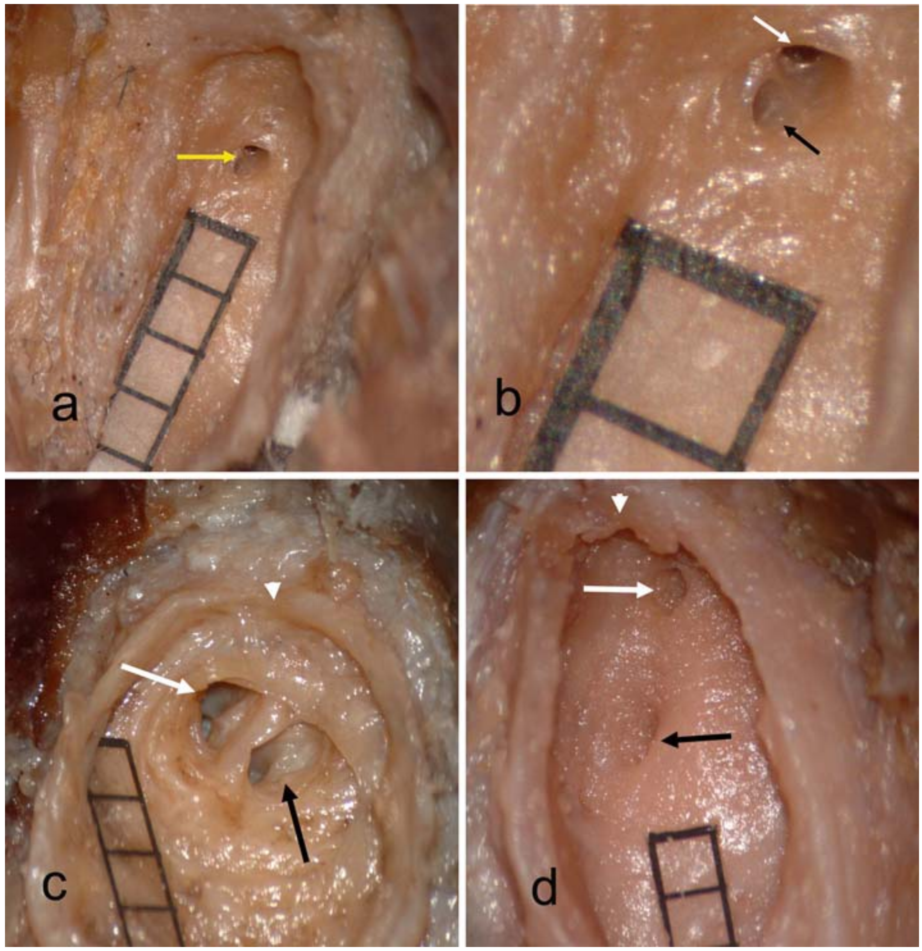

Fig. 5 The opening of the lacrimal canaliculus to the lacrimal sac as Type B, Type C. **a** Common opening was seen in Type B opening. **b** When the image in (**a**) was magnified, the upper and lower canaliculus' joining at the wall of the lacrimal sac and entering the sac through a common hole could be seen. **c** Type C opening, the upper and lower canaliculus were close to each other but enter the sac separately. **d** Type C opening, the upper and lower canaliculus were far entering the sac. *Big arrow*: the common hole, *white arrow*: the upper lacrimal canaliculus, *black arrow*: the lower lacrimal canaliculus

Table 2 Comparison of the opening types of the lacrimal canaliculus to the lacrimal sac with the literature

Authors	Type A (%)	Type B (%)	Type C (%)
Tucker et al.	83	–	17
Caldemeyer et al.	100	–	–
Kurihashi et al.	100	–	–
Yazici et al.	94.1	3.8	2
Present study	85	5	10

Yazici and Yazici demonstrated for their dacryocystographic study that the lacrimal sac enlargement secondary to nasolacrimal duct obstruction changed the anatomic position of the CC in their patients. The CC found to bend inferiorly after the canaliculi and followed a superior to inferior course to enter the sac [32]. That anatomic curve may prevent the reflux of the sac. It appears that the wall drags the medial end of the CC inferiorly and laterally as it expands. Yazici and Yazici suggested as Tucker et al. that obstruction may have resulted from the anterior angulation of the CC. Therefore, they concluded that performing the probing through the ULC conformed to anatomic structure better and it could also be less traumatic [31].

It has been previously reported that there are many valves in the drainage system [2, 11, 23, 30]. However, in this study, no such valves were found like Kurihashi et al. [14]. In our opinion, these findings indicate that a normal lacrimal drainage system can function through a small and narrow common canalicular space, and the inner space of the canaliculus do not exhibit variations in size.

This study has provided measured objective criteria concerning the lacrimal drainage system, and these are crucial during surgery. The findings about the landmarks and side symmetry are to be carefully considered. No differences at a significance level of $P > 0.01$ have been observed in the comparison of right–left side the data for all the parameters. We had a difficult in comparing our findings to those of the previous studies since they had not given detailed parameters. The only comparison was made to that of Yazici and Tucker, as it examined the same region (Tables 2, 3). In our study, important parameters were given concerning the CC and the lacrimal sac. Type A, where the ULC and the LLC form the CC before opening to the lacrimal sac, was seen by 85%. During dacryosystography, the CC in Type B may be confused with Type C in radiological examinations, as it is too short. This situation may be seen with 5% frequency

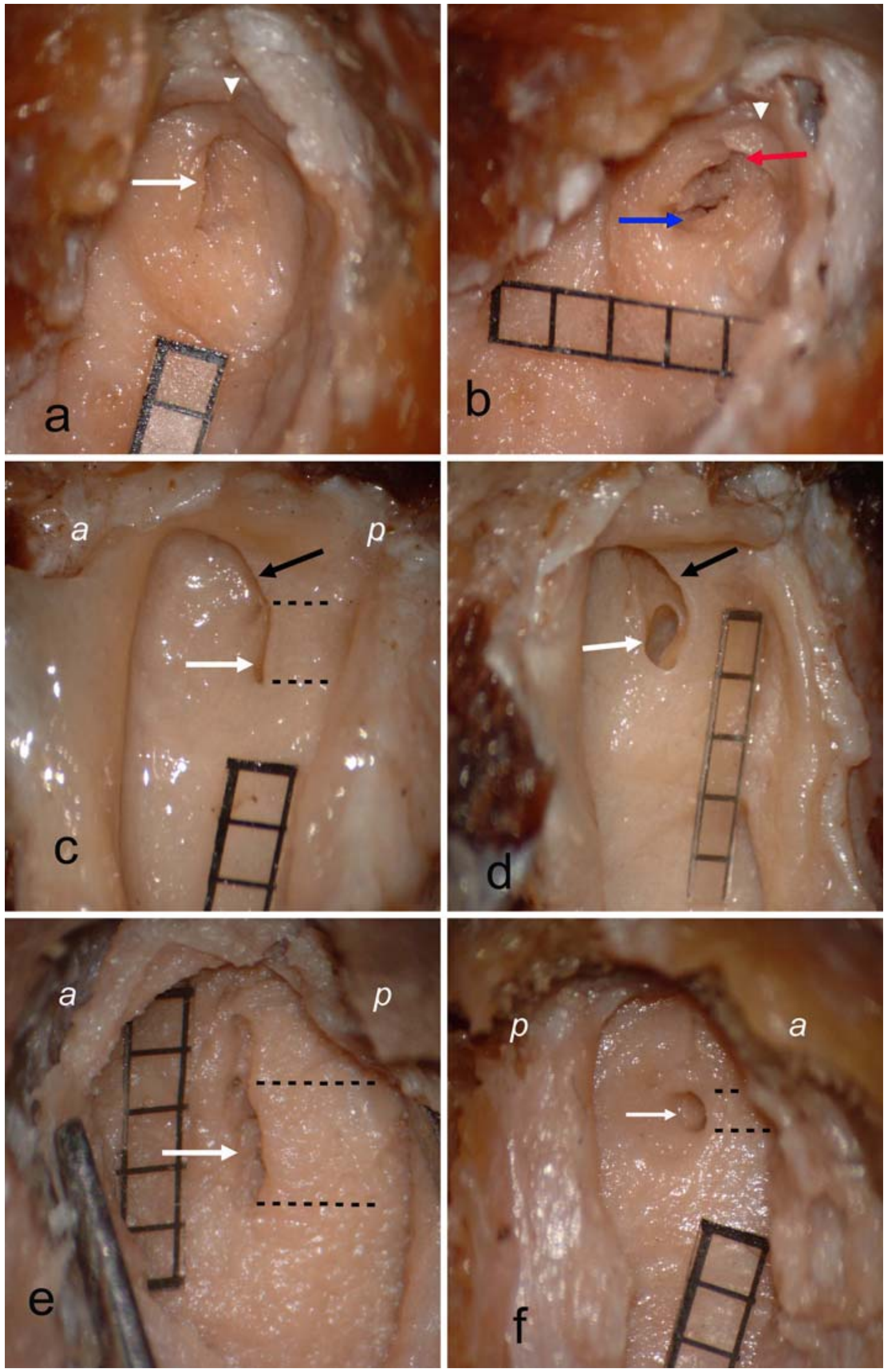

Fig. 6 **a** The opening hole of the CC to the sac viewed from the medial. **b** The common canaliculus opened and viewed from the front and inside and a very short common canaliculus was present. Due to this shortness it might be misinterpreted as Type C in radiological examination. **c** The view of the common canaliculus from the medial in a posterior to anterior direction and opening to diverticulum. **d** The common canaliculus was seen when diverticulum was opened (view from the inner-front side). **e** Opening of the common canaliculus from posterior to anterior direction. **f** Opening of the common canaliculus from anterior to posterior direction. *Arrow head*: the ornix of the lacrimal sac; *white arrow*: common canaliculus; *big white arrow*: the upper lacrimal canaliculus; *big black arrow*: the lower lacrimal canaliculus; *black arrow*: diverticulum; *intermittent lines*: projection of the common canaliculus. *a* anterior, *p* posterior

and may cause lacrimal canaliculus to get harmed. In radiological viewing methods, the CC and the common opening might be confused and affect the surgical procedure in a negative way. The opening angles of the CC with the lacrimal canaliculus; the ULC with the lacrimal sac and the ICL with the lacrimal sac were evaluated. In all types, convergence was detected to be an acute angle. It was not possible for us to compare these results with former studies as the opening angles of ULC with the lacrimal sac and the ICL with the lacrimal sac have not been mentioned in detail regarding the incidences and classification (Table 3).

Macroscopically we have not observed the anatomical structure called the Rosenmuller valve. We think that the most important mechanism that prevents liquid reflux from the lacrimal sac is the entry angle of the lacrimal canaliculus into the lacrimal sac. This mechanism can be

Table 3 Comparison of the measurements belonging to the opening angle of lacrimal canaliculus to the lacrimal sac with the literature

The opening angle	Tucker et al. (%)	Present study (%)
Common canaliculus to the lacrimal sac		
Acute angle	100	72
Right angle	–	22
Obtuse angle	–	6
Upper lacrimal canaliculus to lacrimal sac		
Acute angle	–	50
Right angle	–	50
Lower lacrimal canaliculus to lacrimal sac		
Acute angle	–	100

likened to the urinary bladder's becoming full and pressing the intramural part of ureter and preventing reflux. The canalicular anatomical type can be evaluated better in the early phases of dacryocystography, during which the lacrimal sac is not distended completely with the contrast media yet. The mechanism responsible for preventing reflux sac contents in certain cases of dacryocystitis, lacrimal sac mucocele and acute dacryocystic retention may be related to the previously unrecognized anatomical configuration of the canalicular system [29].

As a result, anatomical landmarks of the lacrimal drainage system may affect the diagnostic and surgical procedures involving the lateral nasal region. It is an indisputable fact that the success of surgical strategy and planning mainly relies on the surgeon's knowledge of the landmarks of the lacrimal sac, gaining the right orientation even at the initial stages of surgery, preventing a wide incision, keeping the surgery time shorter and avoiding serious complications such as epiphora. This study may provide information about the anatomical orientation of the lacrimal outflow obstruction for clinical management.

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