• Clinical Research •

Anatomic characteristics of the lacrimal sac and adjacent bony structures–a computed tomographic-dacryocystography research

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Abstract

● **AIM:** To describe the anatomic characteristics of the lacrimal sac and its adjacent bone structures and to provide surgical recommendations for endoscopic dacryocystorhinostomy (EN-DCR).

● **METHODS:** This retrospective comparative study involved 118 sides with complete nasolacrimal duct obstruction and 83 unaffected sides from 126 patients. Computed tomographic-dacryocystography (CT-DCG) scans were performed before lacrimal surgery, and image reconstruction was used to obtain continuous 0.75-mm axial, coronal, and segmental sections for review. The morphology of the lacrimal sac and its relationship with adjacent bony structures were determined for measurement, as well as the obstructed location.

● **RESULTS:** The height of the lacrimal sac was 12.99±2.10 mm in this study. The operculum of the middle turbinate (OMT) was located vertically in the lower third of the lacrimal sac. Horizontally, the junction between the maxillary bone and the lacrimal bone (MB-LB) was close to, mostly (60.2%) posterior to, the lacrimal sac. The uncinate process was more frequently attached to the lacrimal bones (75.1%). The obstructions were generally located around the entrance of the nasolacrimal duct (NLD). However, some were placed higher, with 7.63% blocked not lower than the OMT. There was a negative correlation between the diameter of the lacrimal sac and the level of obstruction (r=-0.35, P<0.01).

● **CONCLUSION:** In this study, the OMT and MB-LB can be served as the landmarks in EN-DCR. Partial uncinectomy should be performed in most cases. The obstructions were generally located around the entrance of the NLD, but some extreme individual variations strongly implies the importance of CT-DCG scanning before surgery.

● **KEYWORDS:** lacrimal sac; nasolacrimal duct obstruction; endoscopic dacryocystorhinostomy; computed tomographic-dacryocystography

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INTRODUCTION

Nasolacrimal duct obstruction (NLDO) is a common condition that can cause excessive tearing and mucopurulent discharge in patients. Complications such as keratitis, severe corneal ulcers, acute dacryocystitis, or orbital cellulitis may occur due to chronic dacryocystitis if NLDO is not correctly diagnosed and treated appropriately[1-2]. Although there is no consensus on the most effective technique for the management of NLDO, endoscopic dacryocystorhinostomy (EN-DCR) should be recognized as the preferred treatment option due to its relatively high success rate (81%-96%) and absence of facial scar[1,3]. The key to achieving a successful EN-DCR is complete exposure of the lacrimal sac, and this requires a comprehensive understanding of the anatomy of the lacrimal drainage system, as well as the pertinent

relationships between the lacrimal sac and adjacent intranasal bony structures prior to surgery. It is very necessary to deeply understand the surgical anatomy and individual variation before performing the surgery.

Computed tomography (CT) is widely accepted as a helpful measurement prior to EN-DCR. Previous studies using CT have described the unique characteristics of Asian populations in terms of the anatomy of the lacrimal sac fossa and its adjacent bony structures. such as the operculum of the middle turbinate (OMT), the junction between the maxillary bone and the lacrimal bone (MB-LB), the uncinate process (UP), and the agger nasi (AN) cell[4-7]. Asians usually have thicker bones, shallower nasolacrimal duct lumens, and narrower intranasal structures, making surgery manipulation more difficult and requiring a comprehensive understanding of the anatomy of the lacrimal drainage system before surgery. It is crucial to emphasize that all these studies highlight the bony nature of the fossa of the lacrimal sac.

As we know, CT scans, although valuable in revealing bony structures, are limited in assessing the specific size and characteristics of the cystic structure of the lacrimal sac. However, it is this precise information that holds paramount importance for surgeons, guiding the exact location for incisions and the design of the ostium. With the aid of contrast agent, computed tomographic-dacryocystography (CT-DCG) not only can provides accurate location of the lacrimal drainage system but also offers valuable information about the pathologies and their specific locations[8].

In our study, we performed CT-DCG in Asian patients diagnosed with primary acquired NLDO (PANDO) before undergoing EN-DCR, capturing images on both the affected and unaffected sides. This approach allowed us to comprehensively describe the morphology of the lacrimal sac (*e.g.,* height and width), the relationship between the lacrimal sac and its adjacent structures (the OMT, MB-LB, UP, AN cell) and the summary of the distribution of the obstructed points, shedding new light on the intricacies of this crucial anatomical area.

PARTICIPANTS AND METHODS

Ethical Approval The study was approved by the Ethics Committee of Eye and ENT Hospital of Fudan University. All patients had provided their written informed consent to surgery and routine preoperative CT scan.

Participants Enrollment In this retrospective case-controlled study, records were collected from Chinese patients who underwent orbital CT-DCG scans before lacrimal surgery between January 2021 and June 2022. Inclusion criteria for this study included unilateral or bilateral PANDO. Exclusion criteria included acute dacryocystitis, canalicular obstruction, previous lacrimal surgeries, lacrimal cysts, functional epiphora, rhinitis, and secondary NLDO induced by tumor, trauma, sarcoidosis, or Wegener's granulomatosis. Two hundred and one eyes from 126 adult candidates were enrolled, including 75 bilateral cases. Then they were divided into two groups: Group A (118 sides) included the affected eyes of patients with unilateral or bilateral primary acquired NLDO patients; and Group B (83 sides) included the unaffected eyes of patients with unilateral PANDO.

Computer Tomodensitometry-Dacryocystography Scan Method The patients underwent a CT-DCG scan using a 128 slice dual source high resolution scanner (Siemens Somatom Definition Flash, Siemens, Germany). Contiguous 0.75 mm axial sections of the orbits parallel to the bilateral infraorbitomeatal lines and coronal and sagittal scans were acquired using a bone window algorithm (width: 4000; level: 700). The patients were placed in a supine position and a plain CT scan was performed prior to any operative procedure. Subsequently, each canaliculus of the patient was probed and injected with ioversol (320 mg/mL) as contrast agent, followed by a second CT scan 5min later. After scanning, saline solution was injected into each canaliculus to remove ioversol.

Computer Tomodensitometry Scan Analysis In this study, axial sections from lower to upper levels were examined. Parameters were measured at three levels: lower reference level (LRL, where lacrimal sac turns into nasolacrimal duct (NLD), Figure 1A), intermediate reference level (IRL, defined by onset of middle turbinate's insertion into nasal fossa wall, Figure 1B), and upper reference level (URL, highest section with contrast in lacrimal sac, Figure 1C). The lacrimal sac's length (URL to LRL) and width (IRL transverse diameter), and nasolacrimal duct entrance width (LRL level) were measured.

The position of the OMT relative to the lacrimal sac was assessed vertically (distance from lacrimal sac top to OMT between URL and IRL; from OMT to NLD entrance between IRL and LRL) and horizontally at IRL (Figure 1E). The UP location in relation to the lacrimal sac was classified at each level based on a previous method into four categories[4] (Figure 1F). Comparisons were made with two prior studies.

Previous research has indicated a strong association between the UP and the AN cell. We conducted an investigation into the presence of the AN cell[9]. We specifically focused on the common canaliculus region, following the methodology established by Soyka *et al*[10]. We explored the existence of the AN cell within the axial, coronal, and sagittal planes.

In this study, the obstruction site was evaluated in group A and classified into three subgroups: 1) upper lacrimal sac obstruction, in which the obstruction was located above or

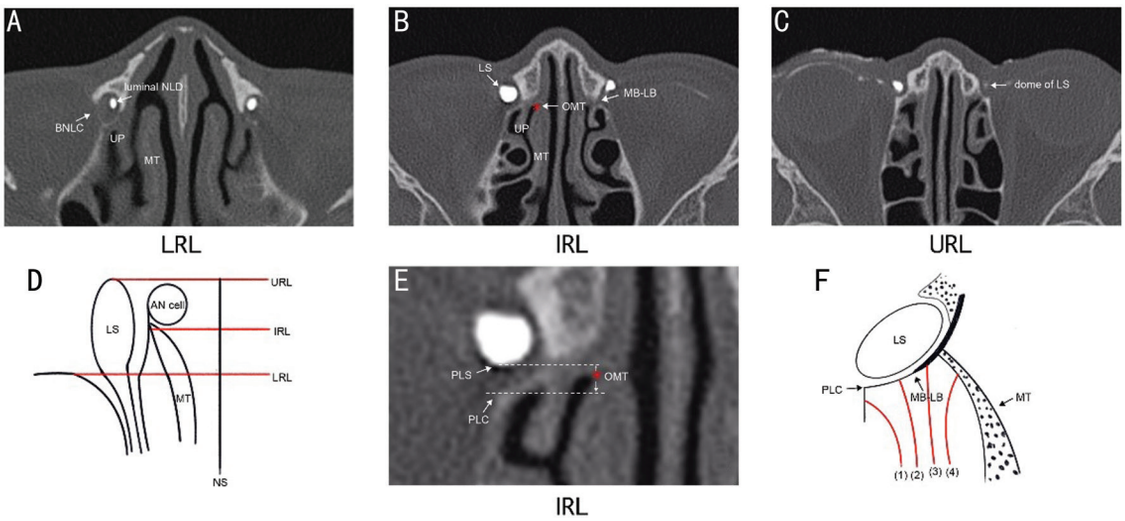

Figure 1 Axial sections of the computed tomography scan and schematic drawings that illustrate the lacrimal sac and adjacent structures at three different levels A: The LRL shows the lowest section in which the LS turns into a NLD, where the entrance of the BNLC can be detected. The contrast agent describes the lumen of the NLD. B: The IRL shows the OMT (red asterisk) and the insertion of the MT into the lateral wall of the nasal fossa. The junction between the MB-LB can be detected at this level. The MT and the UP can be detected at both URL and IRL. C: The URL indicates the dome of the lacrimal sac, which is the highest section where the contrast agent is observed. D: Schematic drawing of the three reference levels and relative relationship of the lacrimal sac, MT, and AN cell. E: In IRL, two horizontal dotted lines tangent to the PLC and the PLS are drawn. The distance between the OMT (red asterisk) and the two white dotted lines is determined as the distance between the OMT and PLC (the lower line) or PLS (the upper line). F: Schematic drawing of the various locations of the UP to the lacrimal sac in the IRL. The insertion of UP could be retrolacrimal (1), lacrimal (2), maxillary (3) or turbinal (4), depending on the location of the PLC, MB-LB and MT. LRL: Lower reference level; LS: Lacrimal sac; NLD: Nasolacrimal duct; IRL: Intermediate reference level; BNLC: Bony nasolacrimal canal; OMT: Operculum of the middle turbinate; MT: Middle turbinate; UP: Uncinate process; URL: Upper reference level; MB-LB: Maxillary bone and the lacrimal bone; AN: Agger nasi; PLC: Posterior lacrimal crest; PLS: Posterior wall of the lacrimal sac; NS: Nasal septum.

equal to the IRL; 2) lower lacrimal sac obstruction, where the obstruction was higher than or equal to the LRL, but below the IRL; 3) NLD obstruction, indicating that the obstruction was lower than the LRL.

Statistical Analysis The age of the patient and the measured values were expressed as mean value±standard deviation. The gender distribution was compared using a χ^2 test. All data was measured three times by the same observer and the average value was recorded for statistical analysis. The measurement results between the two groups were calculated with a Student's *t* test or Wilcoxon-Mann-Whitney test, depending on whether the data were continuous or not. The correlation between the obstructed level and the transverse diameter of the lacrimal sac was calculated using Pearson's correlation. Statistical significance was considered with a P value <0.05.

RESULTS

Demographics A total of 201 eyes from 126 PANDO patients were enrolled in this study; 118 eyes from 99 patients were classified into Group A (90 females/9 males; mean age 56.64±12.64y) and 83 eyes from 83 patients were classified into Group B (68 females/15 males; mean age 57.04±12.31y). The age of the patient (P=0.83) and the sex ratio (P=0.07) were similar between the two groups. In Group A, the patients had been complaining of epiphora for a duration ranging from 0.25 to 40y (median: 5y). Of the 99 patients enrolled, 97 eyes in 81 patients were accompanied by chronic dacryocystitis.

Morphology of the Lacrimal Sac In the summarized data of Table 1, the average lacrimal sac height was 12.99 mm for all eyes, with no significant difference between Group A (13.19 mm) and Group B (12.70 mm). Significant differences were observed in the transverse diameter of the lacrimal sac at IRL (Group A: 6.55 mm, Group B: 1.81 mm) and LRL (Group A: 2.02 mm, Group B: 1.21 mm). However, at the NLD entrance, both transverse and anteroposterior diameters showed no significant differences between the groups.

Location of the OMT In our study, we assessed the vertical and horizontal relationship between the OMT and the lacrimal sac. Vertically, the OMT insertion into the nasal wall was typically in the lower third of the lacrimal sac, positioned 8.18±2.77 mm below the superior margin (URL) and 4.82±2.79 mm above the bony nasolacrimal canal (LRL) among the 201 eyes. We investigated whether obstruction influenced the vertical OMT placement but found no statistically significant differences between Group A and Group B. In some instances, the OMT was even level with (5 cases; 2.49%) or below (4 cases; 2.00%) the LRL.

Table 1 Measurement of the lacrimal sac and nasolacrimal duct

Parameters	Group A	Group B	*P*
Height of lacrimal sac (mm)	13.19±2.05	12.70±2.13	0.10
Transverse diameter of NLD in LRL (mm)	5.58±0.77	5.46±0.87	0.29
Anteroposterior diameter of NLD in LRL (mm)	6.70±1.05	6.65±1.09	0.78
Transverse diameter of NLD lumen in LRL (mm)	2.02±1.14	1.21±0.58	<0.01[a]
Transverse diameter of lacrimal sac in IRL (mm)	6.55±14.65	1.81±0.73	<0.01[a]
Distance between the OMT and URL (mm)	8.42±2.73	7.82±2.80	0.13
Distance between the OMT and LRL (mm)	4.61±2.82	5.11±2.73	0.21

Group A: obstructed sides of patients with unilateral or bilateral primary acquired nasolacrimal duct obstruction patients (PANDO); Group B: Unobstructed sides of patients with unilateral PANDO; NLD: Nasolacrimal duct; LRL: Lower reference level; IRL: Intermediate reference level; URL: Upper reference level; OMT: Operculum of the middle turbinate. [a]Significant statistical difference.

Table 2 Comparison of the position of the UP in published CT scan reports and this study *n* (%)

Reference level and study	Retrolacrimal	Lacrimal	Maxillary	Turbinal
URL				
Fayet study (*n*=77)	4 (5.2)	4 (5.2)	22 (28)	47 (61)
Woo study (*n*=152)	0	0	35 (23)	117 (77.0)
Current study (*n*=201)	0	2 (1)	60 (29.9)	139 (69.2)
IRL				
Fayet study (*n*=77)	4 (5.2)	18 (23)	43 (55.8)	12 (15)
Woo study (*n*=152)	0	17 (11.1)	98 (64.5)	37 (24.3)
Current study (*n*=201)	0	33 (16.4)	150 (74.6)	18(9)
LRL				
Fayet study (*n*=77)	25 (32)	35 (45)	17 (22)	0
Woo study (*n*=152)	0	122 (80.3)	30 (19.7)	0
Current study (*n*=201)	2 (1)	151 (75.1)	48 (23.9)	0

URL: Upper reference level; IRL: Intermediate reference level; LRL: Lower reference level; UP: Uncinate process.

Horizontally, the OMT was commonly anterior to the posterior lacrimal crest (PLC; 153/201 eyes) but posterior to the PLS (136/201 eyes). The distance between the OMT and the PLC showed no significant difference between the two groups; however, in Group A, the OMT was closer to the PLS compared to Group B.

Position of the MB-LB At the IRL level, we measured the anteroposterior relationship between the lacrimal sac and MB-LB. In Group B, around 70% (58/83 eyes) had the lacrimal sac in front of the MB-LB, while in Group A, this decreased to 53.39% (63/118 eyes; $P<0.01$), with the lacrimal sac's posterior wall often behind the MB-LB. We also assessed the relative position of the OMT and MB-LB; in both groups, the OMT was more frequently posterior to the MB-LB (Group A: 77.97%; Group B: 77.11%). The distance between the OMT and MB-LB showed no significant difference between the groups (1.28±2.24 mm in Group A *vs* 1.10±1.90 mm in Group B; $P=0.56$).

Relationship Between Lacrimal Sac and UP The relative relationship between the lacrimal sac and the UP was determined at all three reference levels. In our study, 201 eyes were examined and it was revealed that there was no statistical difference between Group A and B at any of the reference levels. The UP was inserted mainly into the lacrimal (75.1%) or maxillary (23.9%) bone at the LRL. At the IRL, it was attached to the lacrimal (16.4%), maxillary (74.6%) or turbinal (9%) bone. In the URL, the UP was inserted primarily into the turbinal bone (69.2%) or the maxillary bone (29.9%). Our results, combined with previously published studies of the UP position, are summarized in Table 2.

Presence of Agger Nasi Cell Out of the 201 eyes, 173 demonstrated the presence of an AN cell, resulting in an incidence rate of 86.07%. In axial CT scans at the common canaliculus level, the AN cell predominantly occupies the posterior nasal aspect of the lacrimal sac. In typical coronal images, the AN cell is situated slightly above and on the inner side of the lacrimal sac. From the sagittal plane perspective, the AN cell is situated in the upper posterior aspect of the lacrimal sac.

Location of the Obstruction Of the 118 eyes in Group A, the average obstructed point was located 0.48±3.42 mm below the LRL. Scatter plots in Figure 2 showed the distribution of the

Table 3 Location of the obstruction in obstructed patients of the nasolacrimal duct

Classification	Numbers	Proportion (%)	Average distance (mm)	Range (mm)
Upper lacrimal sac obstruction	9	7.63	1.92±2.13[a]	0.00-6.00
Lower lacrimal sac obstruction	49	41.53	1.58±1.60[b]	0.00-6.00
NLDO	60	50.85	3.14±1.80[c]	0.75-9.00

[a]Distance from the obstructed point in upper lacrimal sac to IRL; [b]Distance from the obstructed point in lower lacrimal sac to LRL; [c]Distance from the LRL to the obstructed point in nasolacrimal duct. IRL: Intermediate reference level; LRL: Lower reference level; NLDO: Nasolacrimal duct obstruction.

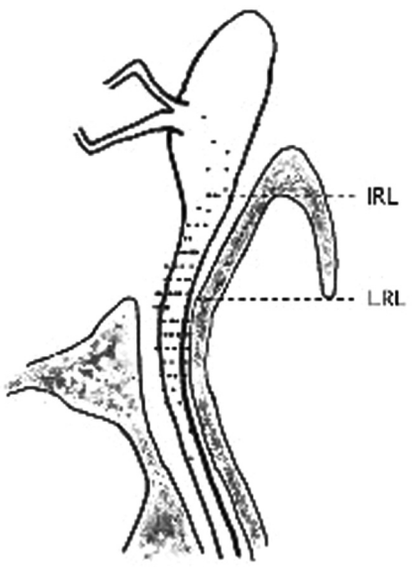

Figure 2 Schematic drawing showing the relative position of the obstructed points in the lacrimal drainage system The obstructions, marked as scattered dots, spread across the lacrimal sac and the nasolacrimal duct. The IRL and LRL are labeled. Illustration by Xinning Cui (non-author contributor). IRL: Intermediate reference level; LRL: Lower reference level.

obstructed point in the lacrimal drainage system in this study. The average and range of distances between the obstructed point and the 3 reference levels are listed in Table 3. In specific cases, we took extra care in categorizing obstructions. One case had the OMT, LRL, and obstruction all in the same axial CT plane and was classified as NLD obstruction. In another case, even though the contrast agent was cut off at the OMT level, it was positioned 4.5 mm below the LRL, leading to its classification as NLD obstruction.

We also found that obstruction level and lacrimal sac diameter at the IRL were negatively correlated (r=-0.35, P<0.01), suggesting lower obstructions are associated with larger lacrimal sac diameters at the OMT level.

DISCUSSION

Performing EN-DCR in Asians can be complex, requiring a deep understanding of the obstructed lacrimal system's structure and variations. This study utilized CT-DCG to assess the lacrimal sac and intranasal characteristics in PANDO patients. Measurements included the lacrimal sac's size and its position relative to OMT, MB-LB, and UP. These findings were used to establish safe osteotomy guidelines for Asian patients. Additionally, the study explored obstruction points within the lacrimal sac, finding a negative correlation between lacrimal sac diameter and obstruction level, highlighting unique obstruction characteristics in the Asian population.

The average height of the lacrimal sac in our study was approximately 13mm, which was close to but slightly different from what was measured in Fayet *et al*'s[4] study (12 mm) or Woo *et al*'s[5] study (11 mm) in Asians. This difference may be attributed to our CT-DCG methodology, offering more explicit contours of the upper lacrimal sac compared to previous plain CT scans. We used a CT machine with ultrathin sections (0.75 mm), providing more accurate data. Racial differences could also play a role, as our data was shorter than in studies among Caucasians, like Rajak and Psaltis's (16 mm)[11-13].

The entrance width of the NLD, both transversely and anteroposteriorly, showed no statistical difference between obstructed and unaffected eyes in our study, aligning with previous research[14-15]. This suggests that bony anatomy may not strongly correlate with PANDO etiology. However, we observed a significant increase in the lacrimal sac width (determined by transverse diameter of contrast agent in IRL) in Group A compared to unaffected eyes. Prior studies have noted enlargement of the lacrimal sac fossa, thickened periosteum, and fibrosis in chronic PANDO patients[16-17]. Whether the lacrimal sac size changes dynamically with chronic inflammation progression or if different etiologies lead to varying developments warrants further investigation.

The OMT, a crucial landmark in DCR to locate the lacrimal sac, traditionally marked the sac's upper limit with most studies showing only 0-20% of the sac above it[18]. Advanced imaging reveals significant racial variations, with a large part of the sac often extending 4-10 mm above the OMT[4-5,9,11-12,19]. Our CT-DCG study found the OMT in the lower third of the vertical lacrimal sac, approximately 8 mm below the uppermost sac and 5 mm above the bony nasolacrimal canal. This precision is vital for surgical planning in EN-DCR, as adequate bone removal above the OMT is necessary for full lacrimal sac exposure. Notably, in some cases, the OMT is as low as or lower than the NLD entrance, with about 4.48% of lacrimal sacs entirely above the OMT. These variations highlight the importance of

preoperative imaging in EN-DCR to accurately determine the lacrimal sac's vertical limits.

The maxillary line, considered an important intranasal landmark in EN-DCR, typically serves as the posterior limit for horizontal incisions in nasal mucosa. Previous studies have indicated that the lacrimal sac is usually situated lateral to the MB-LB suture line, and the OMT is generally anterior to the MB-LB[4,20]. However, our study uncovered some variations. In approximately 70% of cases in Group B, the lacrimal sac was positioned anterior to the MB-LB, although this proportion decreased to 53.39% for obstructed eyes. This difference might be attributed to lacrimal sac enlargement due to obstruction. Thus, it can be inferred that while the posterior wall of the lacrimal sac may occasionally be slightly posterior to the MB-LB, most lacrimal sacs are anterior to the MB-LB. This suggests that the MB-LB remains a reliable posterior boundary for ostium placement in the Asian population.

The UP is an important intranasal structure adjacent to the lacrimal sac. Previous studies had varied opinions about whether uncinectomy is necessary or not during EN -DCR[4,21]. This research investigated the attachment of UP, finding that it was connected to the lacrimal bone at the LRL in 75.1% of cases, a rate higher than in other races[4], but which is consistent with certain Asian studies[5,9]. This supports the idea that partial uncinectomy should be considered in Asian patients in most of the cases[5,9]; meanwhile, the UP can also serve as a landmark to approach the lower part of the lacrimal fossa[5].

In our study, we observed an AN cell incidence rate of 86%, in line with established ranges[10,22-23]. We specifically examined the AN cell at the common canaliculus level using contrast agents and explored its relationship with the lacrimal sac in different planes. This suggests that the AN cell may overlap with the upper part of the lacrimal sac. When performing EN-DCR and aiming to fully open the lacrimal sac up to the common canaliculus level, opening the AN cell might also be necessary. Further research is needed to explore this overlap and its potential impact on EN-DCR surgery.

Using CT-DCG scans, this research studied the obstructed positions of all PANDO patients and found that the most common obstructed sites were around the entrance to the NLD, which is consistent with previous studies[24-25]. Individual variations in the levels of obstructions were also observed, with almost half of the obstructions occurring in the lacrimal sac, at a site higher than the entrance of the NLD. There were 7.63% of cases with obstructions located at or higher than the OMT, which is quite a high position in the nasolacrimal passage system. Furthermore, it was highlighted that a higher position of obstruction is usually associated with a shallower lacrimal sac, which can pose a challenge during surgery. Thus, it is essential to perform CT-DCG scans before the operation to identify the obstructed point and measure the length and width of the lacrimal sac, while observing the anatomical details of the adjacent structures. In this way, a personalized surgical plan can be created that is tailored to precise bony removal and adequate lacrimal exposure.

Our study has limitations, including a relatively small sample of about 200 cases, which may not fully represent the variation in positions of the OMT, MB-LB, UP, and obstruction points. Additionally, it excluded cases with obstructions above the lacrimal sac, a potential area for future research.

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Data availability statement: Data are available on reasonable request. The deidentified datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: Cui XH, None; **Fang YW,** None; **Zhang LM,** None; **Qiu JN,** None; **Zhang CR,** None; **Wang Y,** None.

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