Analysis of lacrimal duct morphology from cone-beam CT dacryocystography in a Japanese population

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Research Article

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Abstract

Purpose: The dacryoendoscope is a practical instrument for the examination and the treatment of lacrimal duct obstruction. Nevertheless, being a rigid fiberscope, manipulation of the endoscope is somewhat affected by the patient's lacrimal duct alignment and the skeletal structure of the face. The morphology and inclination of the lacrimal duct differ among individuals and ethnic groups. We aimed to evaluate the alignment of the lacrimal duct from the perspective of endoscopic maneuverability in a Japanese population.

Methods: We retrospectively analyzed the CBCT-DCG images of 102 cases diagnosed with unilateral primary acquired nasolacrimal duct obstruction (PANDO) at Ehime University Hospital from December 2015 to May 2021. We investigated the following parameters of the lacrimal duct on the contralateral side of unilateral PANDO: 1) the angle formed by the superior orbital rim–internal common punctum–nasolacrimal duct opening, 2) the angle formed by the lacrimal sac and the nasolacrimal duct, 3) the length of the lacrimal sac, 4) the length of the nasolacrimal duct.

Results: The measurement results were as follows: 1) 10.2 ± 7.8° (range, −11° to +27°); 2) −6.3 ± 14.1° (range, −43° to +40°); 3) 8.9 ± 2.3 mm (range, 4.3–17.1); 4) 13.2 ± 2.7 mm (range, 5.7–20.7). Of these parameters, values of all except 3) followed a normal distribution.

Conclusions: We reported anthropometric data analyzing the morphology of the lacrimal ducts using CBCT-DCG in a Japanese population. In our cohort, the line from the superior orbital rim through the internal common punctum to the nasolacrimal duct inclined anteriorly in 92% of cases. In such cases, a probe with a bent or curved tip was considered more appropriate than a straight-type probe.

Introduction

The lacrimal duct extends from the lacrimal punctum to the lower opening of the nasolacrimal duct (NLD) on the lateral wall of the inferior nasal meatus. It passes through the upper and lower punctum, the superior and inferior canaliculi, and the common canaliculus to reach the internal common punctum (ICP) on the tear sac. The pathway to this point passes through eyelid tissue that is mobile and elastic. The lacrimal sac (LS) is fixed in the lacrimal fossa, and the interosseous and meatal parts of the NLD are also fixed tissues. Primary acquired nasolacrimal duct obstruction (PANDO) is an organic obstruction of the lacrimal duct that can occur anywhere from the punctum to the opening of NLD on the inferior nasal meatus.[1] Cases with obstruction from the punctum to the ICP are classified as *pre-saccal obstruction*, while cases with obstruction thereafter are classified as *post-saccal obstruction*. Dacryocystorhinostomy (DCR) is the first-line treatment for PANDO. Meanwhile, endoscopic-assisted nasolacrimal duct intubation (ENDI) is widely utilized as a minimally invasive treatment for lacrimal duct stenosis and obstruction in Northeast Asia.[2-5] The ENDI procedure is performed while directly observing the obstructed region in the lacrimal duct with a dacryoendoscopy and observing the inferior meatus in the nasal cavity with a nasal endoscopy (Supplementary Files, Video.1). This procedure reduces complications from iatrogenic false passage formation. Since ENDI can usually be performed under local anesthesia, it has evolved into a less invasive and securer procedure, which is one of the main reasons for its increasingly widespread use in Northeast Asia. Another reason is that Northeast Asians have relatively flat facial features, with a less elevated superior orbital rim (SOR) than other ethnic groups. This allows for relatively easy manipulation of a dacryoendoscope.[6]

The line formed by the SOR–ICP is the anatomical limit where the tip of a straight probe can reach most anteriorly after entering the NLD through the ICP. When the line formed by the ICP–NLD opening was anteriorly inclined to the line formed by the SOR–ICP, blind probing with a straight bougie or manipulating a dacryoendoscope with a straight probe might form an iatrogenic false passage posterior to the original lacrimal duct. Because it is possible to stand the endoscope more vertically than the SOR, but more difficult to tilt it horizontally than the SOR (Fig. 1, 2).

It is reported that the length, morphology, and inclination of the lacrimal duct differ among individuals; there are also differences between races and ethnic groups. [7-12] Hence, the current study investigated the angle of SOR–ICP–NLD opening, LS-NLD inclination, the length of LS and NLD to evaluate the anthropometric features of the lacrimal duct morphology in a Japanese population.

Methods

Patient selection

The subjects of this study were patients diagnosed with unilateral PANDO at Ehime University Hospital from December 2015 to April 2021. Diagnosis was obtained through the irrigation test, dacryoendoscopic examination, and dacryocystography (DCG) with cone-beam computed tomography (CBCT). We retrospectively analyzed the CBCT-DCG images of the contralateral side of 102 patients diagnosed with unilateral PANDO. There were no abnormalities on the contralateral side in any of the above tests. A typical example of a CBCT-DCG image sectioning the lacrimal duct is shown in Fig. 3. The patient had been diagnosed with left-sided unilateral PANDO. Fig. 3 shows a DCG image of the right side, contralateral to the obstructed side.

DCG and CBCT procedures

After topical anesthesia with 4% lidocaine instillation, a 23-gauge curved lacrimal cannula was inserted into the upper and lower punctum. A nonionic, water-soluble contrast agent (1–2 ml; Omnipaque 300® [iohexol]; GE Healthcare, Tokyo, Japan) was manually injected slowly until the patient reported the solution reaching the nasal antrum, or until the contrast agent flowed back from the punctum. CBCT imaging was performed within 10 minutes after injection of the contrast medium. CBCT images were acquired using a 3D Accuitomo F17 (Morita, Kyoto, Japan). The imaging conditions were as follows: scan time, 17.5 seconds; X-ray output, 90 kV and 8.0 mA. The length and angle measurements from the images were made using dedicated computer software (i-Dixel 2.0; Morita, Kyoto, Japan). The images were converted to monochrome to facilitate observation of the contrast media.

Investigated parameters on CBCT-DCG images

The following four parameters were evaluated in CBCT-DCG images of a sagittal section: 1) the angle formed by SOR–ICP–NLD opening (Fig. 4A). The described method was applied to evaluate this angle. A straight line starting from the ICP was drawn in the direction of the SOR; and the tangent point on the SOR was determined. The distal end of the interosseous NLD was defined as the NLD opening. Then, the angle formed by the line connecting the tangent point of SOR–ICP and the line connecting ICP–NLD opening was measured.

The following parameters were also measured: 2) the angle formed by LS–NLD (Fig. 4B); 3) the length from the ICP to the LS–NLD transition (LS length) (Fig. 4C); and 4) the length from the LS–NLD transition to the NLD opening (NLD length) (Figure 4C). Of the above, parameter 2) refers to the angle formed by the long axis of the lacrimal sac and the nasolacrimal duct at the LS-NLD transition. The angles were designated by plus values in the anterior bending type, and by negative values in the posterior bending type. The LS–NLD transition was determined by the sagittal projection of the area corresponding to the origin of the interosseous NLD in the horizontal section of the CBCT image.

Statistical analysis

Data were analyzed using JMP software ver. 16 (SAS Institute, Cary, NC, USA). The Shapiro–Wilk test was used to determine whether measurement data followed a normal distribution; a *p*-value of >0.05 was considered to indicate normality in the distribution. The Mann–Whitney U test was used to test the significance of differences for each parameter between males and females. A *p*-value of <0.05 was considered significant.

Ethical approval and consent to participate

This study and its data collection protocol were approved by the Institutional Review Board of Ehime University (Ethical Approval Number: 1601003). The study was registered with the University Hospital Medical Information Network Clinical Trials Registry (Number: UMIN 000025180). Written informed consent was obtained from each patient before enrollment. All procedures used in this study were performed in accordance with the tenets of the Declaration of Helsinki.

Results

The mean age of the 102 cases was 71.3 ± 11.7 years. Among them, 74 cases were female, and 28 cases were male. There were 51 cases of right-side PANDO and 51 cases of left-side PANDO. The maximum, minimum, and average values of the measured parameters are shown in Table 1.

The angle formed by SOR–ICP–NLD opening

The maximum value of the angle was 27°, and the minimum value was −11°. The mean value was 10.2 ± 7.8°. The angle was positive in 92% (93/101) of cases, while 8% (8/101) of the subjects had a negative angle. An example image of a case with a large SOR–ICP–NLD opening angle is shown in Fig. 5. The large angle was due to the elevation of the SOR and anterior inclination of the NLD. The Shapiro–Wilk test gave a value of 0.55, indicating a normal distribution (Fig. 6A). For females, the mean was 9.9 ± 8.2°; for males, it was 10.8 ± 6.7°. There was no significant difference between males and females ($p = 0.67$).

The LS–NLD angle

The maximum angle was 40° and the minimum was −43°. The mean was −6.3 ± 14.1°. The Shapiro–Wilk test gave a value of 0.30, indicating a normal distribution (Fig. 6B). The anterior bending type represented 33.3% (31/93) of cases; 66.7% (62/93) were of the posterior bending type. Examples of cases with anterior and posterior bending are shown in Figs. 7 and 8, respectively. For females, the mean was −6.9 ± 14.5°; for males, it was −4.6 ± 12.9°. There was no significant difference between males and females ($p = 0.29$).

The length of LS

The maximum value was 17.1 mm and the minimum value was 4.3 mm. The mean was 8.9 ± 2.3 mm. The Shapiro–Wilk test gave a value of 0.0002, indicating a non-normal distribution (Fig. 6C). For females, the mean was 8.7 ± 2.1 mm; for males, it was 9.6 ± 2.6 mm. There was no significant difference between females and males ($p = 0.079$).

The length of NLD

The maximum value was 20.7 mm and the minimum value was 5.7 mm. The mean was 13.2 ± 2.7 mm. The Shapiro–Wilk test gave a value of 0.39, showing a normal distribution (Fig. 6D). For females, the mean was 13.0 ± 2.4 mm; for males, it was 13.7 ± 3.3 mm. There was no significant difference between females and males ($p = 0.17$).

Discussion

Dacryocystorhinostomy (DCR) is the first-line treatment for PANDO in Western countries. Meanwhile, ENDI is extending as a minimally invasive treatment in Northeast Asia (Supplementary Files, Video.1). In general, the long-term therapeutic outcomes of ENDI are not equivalent to DCR. Nevertheless, evidence has accumulated that the outcomes of ENDI are almost as effectual as DCR for canaliculus obstruction and certain forms of PANDO (in cases of non-inflammatory or partial obstruction).[2,4,5,13-15] Since ENDI can be a minimally invasive procedure for the treatment of PANDO, further studies are needed to compare the long-term treatment outcomes of DCR and ENDI in terms of pathological conditions (e.g., site of obstruction, cause of obstruction, and duration of obstruction).

Since it was first reported in 1909, DCG has undergone improvements in contrast media, injection methods, and image capturing methods. DCG is still an essential preoperative evaluation for PANDO.[16,17] Meanwhile, clinical applications of CBCT have gradually increased in the head and neck regions since its first application in dentistry in 1998. CBCT is now widely used in medical facilities for dentistry, oral surgery, and otorhinolaryngology.[18-21] Although there are few reports on CBCT usage in ophthalmology, CBCT-DCG is a practical test for evaluating PANDO. It has the advantage of considerably lower radiation exposure than conventional multi-slice CT-DCG.[22-24]

The lengths, morphologies of the lacrimal duct vary among individuals and between ethnic groups.[7-12] In this study, we examined several parameters of the lacrimal duct using sagittal section of CBCT-DCG images in a Japanese population. Results showed the average angle formed by the SOR–ICP–NLD opening was 10.2 ± 7.8°. As mentioned above, the line formed by the SOR–ICP is the anatomical limit where the tip of a straight probe can reach most anteriorly after entering the NLD through the ICP. We confirmed that in 92% of subjects in our cohort, the line formed by the ICP–NLD opening was anteriorly inclined to the SOR–ICP line. This suggests that blind probing with straight bougies or manipulating a dacryoendoscope with straight probes pose risks for forming an iatrogenic false passage posterior to the original lacrimal duct in this cohort. Therefore, a probe with a bent anterior tip, or a curved probe, would be more appropriate in these cases (Fig. 9). In 8% of the subjects, the SOR–ICP–NLD angle was zero or negative. In such cases, a straight probe is considered more suitable than a bent anterior tip or curved probe.

Generally, Northeast Asians have a low development of the SOR and portray a relatively flat facial appearance. The SOR–ICP–NLD angle in other ethnic groups that have a well-developed SOR may be different from our study's results. By examining several other races and ethnic groups, diversity of SOR-ICP-NLD angles in different ethnic groups will be evident.

Additionally, we investigated the LS–NLD angle and found a mean value of −6.3 ± 14.1° (range, −43° to +40°). The average angle of the anterior bending type (33.3% of cases, Fig. 7) was 8.8 ± 14.1° and that of the posterior bending type (66.7% of cases, Fig. 8) was −13.8 ± 13.3°. Previous studies reported the LS–NLD angle in an anatomical survey of Japanese cadavers, Narioka et al. reported that the anterior bending type accounted for 80% of cases, with an average angle of +8.9 ± 5.0° (range, 0°–19°), and the posteriorly bending type accounted for 20% of cases, with an average angle of −12.3 ± 9.0° (range, −2° to −26°).[25] In contrast, Park et al. reported that the mean LS–NLD angle was −10.3° and that approximately 90% of cases were posterior bending.[26] In this study, our data were provided by a relatively larger number of cases than the previous reports, it is necessary to increase the number of measurements and accumulate data on the LS–NLD angle and the frequencies of anterior and posterior bending variations for attaining more accurate values.

Conclusion

One of the serious complications of ENDI surgery is forming a false passage. The creation of false passage results from the firmness of the obstruction site, but also from the fact that the lacrimal duct often runs beyond the range of motion of the endoscope probe. The maneuverability of the endoscope in the lacrimal sac and the nasolacrimal duct is often interfered with by the elevated SOR. Then, we examined anthropometric data analyzing the morphology of the lacrimal ducts using CBCT-DCG in a Japanese population. The result showed that over 90% of subjects in our cohort, the SOR−ICP−NLD angle was inclined anteriorly, indicating that employing a tip bent or curved dacryoendoscope probe was considered reasonable in reducing SOR interference in these cases.

Declarations

Acknowledgements

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Conflict of interest

The authors declare that they have no competing interests. The authors alone are responsible for the content and writing of the paper.

Author Contributions

JN contributed to conception, data extraction, analysis, and drafting. TK worked for the surgical operations, data extraction, interpretation of the results and drafting. AM and AS contributed to the surgical operations, data acquisition, and interpretation of the results. TK, AM and AS provided statistical advice. NM and AS provided general management of the study. NM and AS critically revised the protocol and main manuscript.

Data availability

The datasets analyzed during the current study are available from the corresponding author (JN) on reasonable request.

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Tables

Table 1. Lacrimal duct parameters measured on sagittal sections of CBCT-DCG images

	1	2	3	4
Parameters	**SOR–ICP–NLD opening angle**	**LS–NLD angle**	**LS length**	**NLD length**
Description	Angle formed by the superior orbital rim, internal common punctum, and nasolacrimal duct opening	Angle formed by the lacrimal sac and the nasolacrimal duct	Length from the internal common punctum to the transition	Length from the transition to the nasolacrimal duct opening
Mean value	10.2±7.8°	−6.3 ± 14.1°	8.9 ± 2.3 mm	13.2 ± 2.7 mm
Maximum value	27°	40°	17.1 mm	20.7 mm
Minimum value	−11°	−43°	4.3 mm	5.7 mm
***p*-value*1**	0.5528	0.3007	0.0002	0.3946
Normal distribution	YES	YES	NO	YES
Mean values of the females	9.9 ± 8.2°	−6.9 ± 14.5°	8.7 ± 2.1 mm	13.0 ± 2.4 mm
Mean values of the males	10.8 ± 6.7°	−4.6 ± 12.9°	9.6 ± 2.6 mm	13.7 ± 3.3 mm
***p*-value*2**	0.6706	0.2862	0.0785	0.1723
Sexual difference	NO	NO	NO	NO

Note: *1 The *p*-value in the normal distribution column was calculated by the Shapiro–Wilk test; $p > 0.05$ indicated that the distribution was normal. *2 The non-parametric Mann–Whitney U test was used to compare the two groups of females and males. The results were considered significant at a *p*-value of < 0.05.

Abbreviations: SOR, superior orbital rim; NLD, nasolacrimal duct; ICP, internal common punctum; LS, lacrimal sac.

Figures

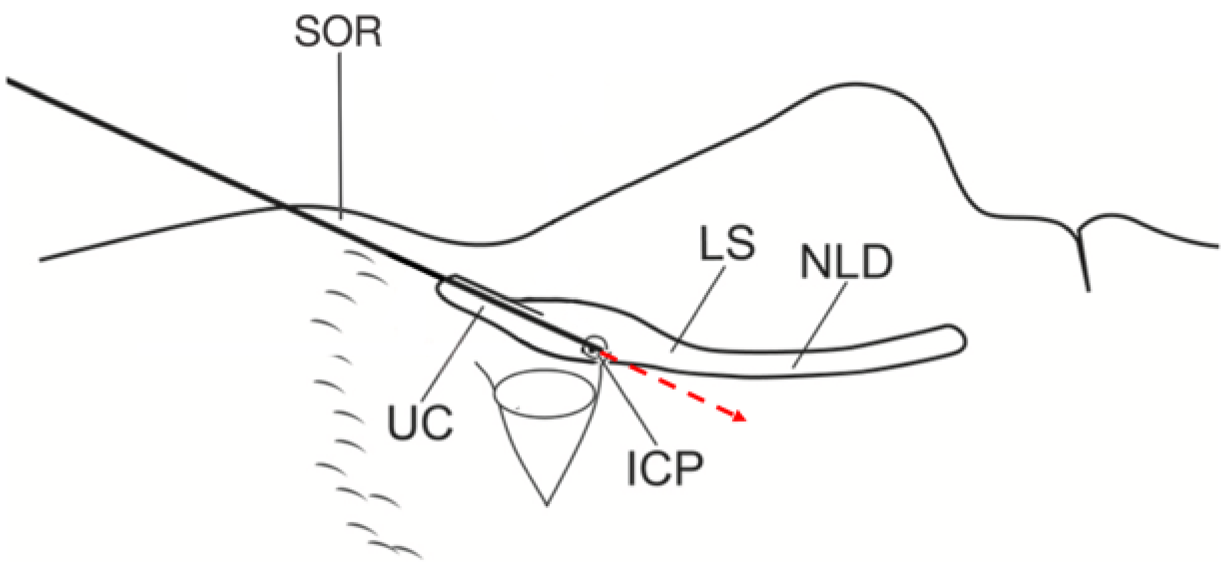

Figure 1

SOR–ICP line as an anatomical limitation

The line formed by the SOR–ICP is the anatomical limit where the tip of a straight probe can reach most anteriorly after entering the LS through the ICP. Red arrow demonstrates when the LS and NLD inclined anteriorly to the line formed by the SOR–ICP as shown in this figure, manipulating straight probes poses a risk for forming an iatrogenic false passage posterior to the original lacrimal duct.

Abbreviations: SOR, superior orbital rim; UC, upper canaliculus; ICP, internal common punctum; NLD, nasolacrimal duct; LS, lacrimal sac.

Figure 2

SOR interference during manipulation of dacryoendoscope

SOR interferes the manipulation of the endoscope. It is difficult to tilt the probe horizontally than the SOR. On the contrary, it is possible to stand the endoscope more vertically than the SOR.

Abbreviations: SOR, superior orbital rim

Figure 3

CBCT-DCG sagittal image sectioning the lacrimal duct

The figure shows a dacryocystographic image of the nasolacrimal duct on the right side, from a patient diagnosed with left-sided unilateral primary acquired nasolacrimal duct obstruction. The original image was converted to monochrome to facilitate observation of the contrast media.

Abbreviations: CBCT-DCG, cone-beam computed tomography–dacryocystography.

Figure 4

Parameters measured in CBCT-DCG images

(A) the angle formed by SOR–ICP–NLD opening. In this case, the line connecting the ICP–NLD opening was inclined anteriorly at 4° relative to the line connecting the SOR–ICP. (B) The angle formed by LS and NLD. In this case, the long axis of NLD was inclined posteriorly at 10° relative to the LS. (C) The length of LS and NLD. In this case, the former was 6.15 mm and the latter was 14.30 mm.

Abbreviations: CBCT-DCG, cone-beam computed tomography–dacryocystography; SOR, superior orbital rim; ICP, internal common punctum; NLD, nasolacrimal duct; LS, lacrimal sac.

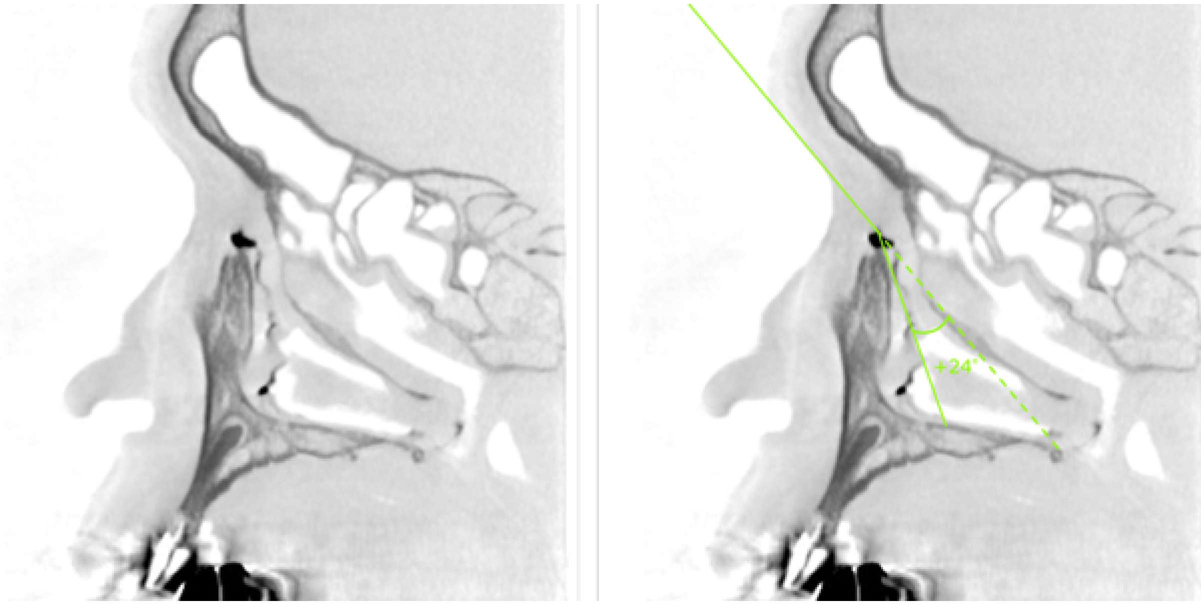

Figure 5

Example of a large SOR–ICP–NLD opening angle

On the left side is the original image. On the right side, a relatively large angle of 24° is seen, due to the elevation of the SOR and the anterior inclination of the NLD.

Abbreviations: SOR, superior orbital rim; ICP, internal common punctum; NLD, nasolacrimal duct.

Figure 6

Test results for normal distribution of the measured parameters

(A) *SOR–ICP–NLD opening angle*: The average angle was 10.7 ± 7.4° (range, −6° to +27°) and followed a normal distribution (p = 0.55). **(B)** *LS–NLD angle*: The mean angle was −6.84 ± 13.7° (range, −43° to +34°) and followed a normal distribution (p = 0.28). **(C)** *LS length*: The mean length was 8.9 ± 2.2 mm (range, 5.4–17.1) and did not follow a normal distribution (p = 0.078). **(D)** *NLD length*: The mean length was 13.3 ± 2.7 mm (range, 5.7–20.7) and followed a normal distribution (p = 0.17). The p-value was determined by the Shapiro–Wilk test. A p-value of >0.05 indicated a normal distribution.

Abbreviations: SOR, superior orbital rim; ICP, interior common punctum; NLD, nasolacrimal duct; LS, lacrimal sac.

Figure 7

Example in which the NLD is inclined anteriorly to the LS (anterior bending type)

On the left is the original image. On the right side, the long axis of the NLD was anteriorly inclined by +14° relative to that of the LS.

Abbreviations: NLD, nasolacrimal duct; LS, lacrimal sac.

Figure 8

Example in which the NLD is inclined posteriorly to the LS (posterior bending type)

On the left is the original image. On the right side, the long axis of the NLD was posteriorly inclined by −21° relative to the LS.

Abbreviations: NLD, nasolacrimal duct; LS, lacrimal sac.

Figure 9

Dacryoendoscope with an anterior bent tip probe and a curved probe

Left: CK10® (Fibertech Co., Ltd., Tokyo, Japan); Middle: CH15C® (Fibertech Co., Ltd., Tokyo, Japan); Right: LAC-06-FY® (Machida Endoscope Co., Ltd., Chiba, Japan)

Supplementary Files

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