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Morphometric Assessment of the Bony Nasolacrimal Canal in Patients with Primary Acquired Nasolacrimal Duct Obstruction by Cone Beam Computed Tomography

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Abstract: *Cone Beam Computed Tomography (CBCT) was employed to evaluate the differences in morphometric parameters of the bony nasolacrimal canals (BNLDs) between primary acquired nasolacrimal duct obstruction (PANDO) patients(patients with primary acquired nasolacrimal duct obstruction (PANDO) (both the affected and unaffected sides) and control subjects (control sides). Seven parameters of bilateral BNLDs were measured retrospectively in 42 unilateral patients (Case group) and 14 controls (Control group). Comparison was made between Case group and Control group for age and gender, and the seven parameters were compared among the affected sides, the unaffected sides and control sides. In both the affected sides and the unaffected sides relative to the control sides, the length of BNLD was significantly longer (p<0.001, p<0.001, respectively), while the angle of NLNF was larger (p<0.001, p<0.001, respectively), and the angle of lacrimal sac-BNLD was smaller (p=0.02, p=0.01, respectively). However, no significant differences were shown between the two sides within patients (all p>0.05). Moreover, other parameters showed no statistical differences among the affected sides, the unaffected sides and the control sides (all p>0.05). There was no statistical difference in any parameters between genders or among different ages within PANDO patients (all p>0.05). A shorter length of BNLD, a larger angle of NLNF, and a smaller angle of lacrimal sac-BNLD in both sides of PANDO patients may be correlated with the occurrence of PANDO. The lack of difference between the affected and unaffected sides of the Case group and some overlap of measured parameters between Case and Control subjects suggest that morphometric changes may be only one of the factors that contribute to the development of PANDO.*

Keywords: *Patients with Primary Acquired Nasolacrimal, Duct Obstruction, Cone-beam computed tomography, Bony Nasolacrimal Canal*

1. Introduction

Dysfunction of lacrimal drainage which is classified as congenital and acquired is attributed to obstruction and stenosis of the nasolacrimal duct.[1] Primary acquired nasolacrimal duct obstruction (PANDO) usually occurs in women aged 40 or over with the symptoms of epiphora and/or dacryocystitis. Several predisposing factors are supposed to contribute to the condition, such as trauma, tumor, surgery, or sarcoidosis. Studies had proposed that changes in the morphology of the bony nasolacrimal duct (BNLD) may be a causative factor for PANDO. Moreover, Takahashi et[2]. al demonstrated that female patients had a shorter transverse diameter (TD) of the BNLD entrance, which may account for the higher occurrence of PANDO in female subjects. However, other studies reported no significant changes in BNLD morphology in PANDO patients[3]. Furthermore, Ramey et al. evaluated the three-dimensional features of the BNLD in a normal population and found no statistical differences in nasolacrimal duct diameter or volume by age, gender, or ethnicity.

It is difficult to conclude whether changes in BNLD dimensions contribute to the development of PANDO due to these controversial results, and these differences may be due to the following reasons:

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on the one hand, the difficulty in two-dimensional measurement of three-dimensional structures, because the measurement of minimum diameter depends on the image plane; on the other hand, the minimum resolution of large spiral computed tomography (CT) is only ~10-15 lp/cm (corresponding to a minimum resolution of 0.33~0.5 mm), so it is with difficult to measure the diameter of nasolacrimal ducts (which is only 3 to 5 mm) with sufficient accuracy[4]. Due to these restrictions, cone-beam CT (CBCT) is increasingly used.

CBCT is diagnostic imaging equipment characterized by higher speed but lower radiation when compared to conventional spiral CT, large-angle three-dimensional stereo imaging, high spatial resolution, and patients' assessment in an upright position. CBCT was initially applied to the study of the facial skeleton, especially in dental surgery and facies maxillaris[5], and has been extended into stomatology for its high contrast bone tissue imaging. In recent years, it has been used in the auxiliary diagnosis of nasolacrimal duct obstructive diseases. Studies[6] have demonstrated that CBCT dacryocystography (DCG) shows good imaging quality of BNLD and can be an adjunct or an alternative tool to conventional DCG for diagnosis of PANDO.

This study used CBCT whose minimum resolution is 50 lp/cm (the minimum discernible object diameter is 0.1 mm)[7] for nasolacrimal duct scanning and measuring, striving to obtain more accurate nasolacrimal duct parameters and comparing PANDO patients with control subjects to determine whether the anatomical variations of the nasolacrimal duct parameters are correlated with PANDO, and thus may be predisposing factors.

2. Subjects and methods

2.1 Subjects

Subjects for the Case group were recruited from unilateral PANDO patients with epiphora who visited the Clinic of Ophthalmology at the First Medical Center of PLA General Hospital between March 2019 and February 2022. Patients were diagnosed by lacrimal irrigation. The Control group was recruited from patients who visited the Department of Stomatology clinic without lacrimal duct obstruction. Bilateral PANDO patients, patients less than 18 years old, and patients with trauma and/or surgery history of the eye or nose were excluded from the study. Finally, 42 unilateral PANDO patients and 14 control subjects were admitted to our study. Both sides of the Case and the Control subjects were measured and the two sides of PANDO patients were designated as the affected side and the unaffected side. Thus, a total of 42 affected sides, 42 unaffected sides, and 28 controls sides were included in the study.

2.2 Methods

All subjects underwent maxillofacial CBCT scans. The gender, age, affected eye, and other information of the two groups of subjects were collected. The anatomical parameters of the nasolacrimal duct in the patients (affected and unaffected sides) and the control subjects were compared.

3. CT scans and parameters

A LARGEV HiReS 3D Cone Beam CT scan was used, with the following settings: 160 mm × 80 mm for the field of view, 0.25 mm for voxel, 100 kV for tube voltage, 4 mA for tube current, 15 s for scan time, and 13 s for exposure time. GE advantage workstations and 3D reconstruction software were used for analysis and measurement of anatomical parameters of the nasolacrimal duct. Measurements were accomplished by the coronal, sagittal, and transverse axial planes of CT scan images, with coronal measurement of deviation of the nasal septum, the angle of relative lacrimal sac-BNLD, and angle of NLNF; sagittal measurement of the length and volume of nasolacrimal duct; transverse axial measurement of the minimum TD, the areas of proximal, minimum and distal end of BNLD. The measurement sites and methods of the parameters of the BNLD are shown in Figure 1.

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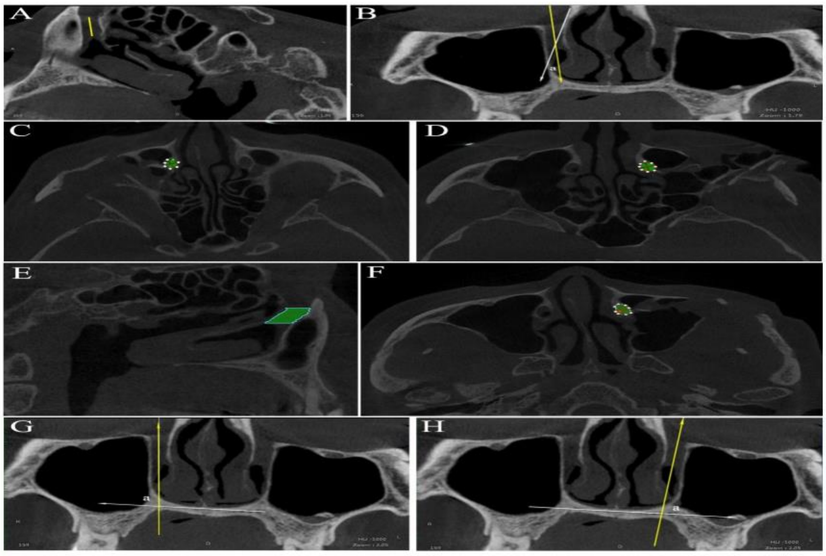
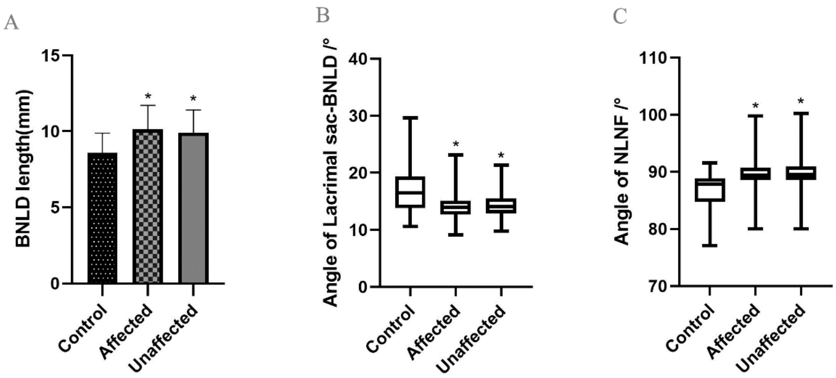


*Sagittal image **(A)** shows the BNLD length (yellow line) measurement. Coronal image **(B)** shows the relative lacrimal sac-BNLD angle (a) between the long axis of the lacrimal sac (white arrow) and BNLD (yellow arrow), respectively. Axial image **(C)** shows the proximal BNLD area (green part) of BNLD. Axial image **(D)** shows the minimum BNLD area (green part) of BNLD. Sagittal image **(E)** shows outlining of BNLD (green line) for BNLD volume calculation. Axial image **(F)** shows the distal end BNLD area (green part) of BNLD. Coronal image **(G)** demonstrates measurement of right NLNF angle (a) between long axis (yellow arrow) of BNLD and nasal floor (white arrow). Coronal image **(H)** shows an assessment of the left NLNF angle (a) between the long axis (yellow arrow) of BNLD and the nasal floor (white arrow). BNLD = bony nasolacrimal duct, NLNF=nasolacrimal duct and nasal floor plane.*

Figure 1: BNLD assessment with CBCT.

4. Anatomical parameters measurement of nasolacrimal duct

The upper border of the BNLD is the juncture of the lacrimal sac and the bony canal, at the frontal process of the maxilla junction with the lacrimal bone, down into Hasner’s valve as the exit of the lacrimal duct in the lower mouth. The length and volume, the minimum TD, the areas of proximal, minimum, and distal end of BNLD, the relative angle of lacrimal sac-BNLD, and the angle of NLNF, as well as the deviation of the nasal septum, were measured for all subjects (Figure 2). The measurement was performed by the same person three times and the average value was taken. Nasolacrimal duct volume was calculated and recorded with GE advantage workstation software.



(A) The BNLD length. (B) Angle of Lacrimal sac-BNLD. (C) Angle of NLNF.
**Comparison between the affected sides or the unaffected sides and the control sides*

Figure 2: Three parameters among groups.

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5. Statistical Analysis

All data were analyzed by GraphPad Prism software version 8.0.2. For the normally and equally distributed data, Student’s t-test was used for comparison between groups and one-way ANOVA with post-hoc Tukey test within groups. The measurements are expressed as the mean ± SD. For the data that were not normally and equally distributed, the Mann-Whitney U rank-sum test was used for comparison between two groups and the Kruskal-Wallis rank-sum test when the analysis was performed for multiple comparisons. The gender difference of the Case subjects relative to the Control subjects was determined with a chi-square test. Statistical significance was denoted when $p<0.05$.

6. Results

6.1 General characteristics of the Case group and the Control group

Eight male and 34 female patients with 3 male and 11 female control subjects were included. The average age was 56.45±15.52 years in the Case group and 52.14±16.47 years in the Control group. No statistical differences were found in gender or age between the two groups ($p=0.51$ and $p=0.85$, respectively; Table 1).

Table 1: Comparison of demographic data between Case and Control groups

Characteristic		Case group (n=42)	Control group (n=14)	t/χ 2	P
Age/yrs		56.45 ±15.52	53.21 ±16.17	0.67	0.51
Gender/n	Male	8	3	0.04	0.85
	Female	34	11		

6.2 Deviation of nasal septum among groups

The rates of the deviated nasal septum between the affected (31.0%) and unaffected (23.8%) sides and control subjects (21.4%) were not significantly different (all $p>0.05$; Table 2).

Table 2: Comparison of anatomic variations between Case and Control subjects

	Patients, both sides [n=84]		Control side, both sides [n=28]	P*	P**	
	Affected side (n=42)	Unaffected side(n=42)				
Deviation of nasal septum, n (%)	13(31.0)	10(23.8)	6(21.4)	0.39	0.38	Deviation of nasal septum, n (%)

* Chi-square test between affected sides and unaffected sides of Case subjects
** Chi-square test between affected sides of Case subjects and both sides of Controls subjects

6.3 Comparison of anatomical parameters in the affected sides, the unaffected sides, and the control sides

Eight parameters of the length and the volume, the minimum TD and the areas of proximal, minimum, and distal end of BNLD, the angle of relative lacrimal sac-BNLD, and the angle of NLNF were all measured. Results showed that the BNLD length in both the affected sides (10.14±1.57 mm) and unaffected sides (9.92±1.48 mm) was significantly longer than that in the control sides (8.59±1.29 mm) ($p<0.001$, $p<0.001$, respectively). The angle of NLNF was larger in in the affected sides [89.50° (88.70°, 91.10°)] and the unaffected sides [89.60°(88.60°, 90.90°)], relative to the control sides [87.80° (84.73°, 88.88°)] ($p<0.001$, $p<0.001$, respectively). The angle of lacrimal sac-BNLD was smaller in in the affected sides [13.95°(12.68°, 15.10°)] and the unaffected sides [14.05°(12.88°, 15.53°)] than that in the control sides [16.45°(13.83°, 19.35°)]($p=0.02$ and $p=0.01$, respectively). However, no significant differences were found in the three mentioned parameters between the affected sides and unaffected sides within Case group. Other parameters were without significant differences among groups (all $p>0.05$; Table 3).

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Table 3: Values of anatomical parameters in the affected sides, the unaffected sides, and the control sides

Parameters	Affected (n = 42) Mean ± SD	Unaffected (n = 42) Mean ± SD	Controls (n = 40) Mean ± SD	P*	Pa	Pb
BNLD length/mm	10.14±1.57	9.92±1.48	8.59±1.29	0.78	<0.001	<0.001
BNLD volume/mm^3	229.9(185.8, 272.8)	210.2(180.0, 288.3)	226.8(202.6, 268.7)	>0.99	>0.99	>0.99
Angle of NLNF / °	89.40(88.50, 90.70)	89.50(88.60, 90.90)	87.80(84.73,88.88)	>0.99	<0.001	<0.001
Angle of Lacrimal sac-BNLD / °	13.95(12.68, 15.10)	14.05(12.88, 15.53)	16.45(13.83, 19.35)	>0.99	0.02	0.01
Area of proximal BNLD /mm^2	20.78(14.73, 26.51)	21.14(17.28, 26.52)	21.05(16.01, 25.92)	>0.99	>0.99	>0.99
Minimum BNLD TD/mm	17.64(14.39, 23.66)	18.87(16.88, 23.58)	18.46(15.94, 24.74)	0.79	0.17	0.43
Area of minimum BNLD /mm^2	19.81±6.78	20.79±7.13	20.59±6.07	>0.99	>0.99	>0.99
Area of distal end BNLD /mm^2	37.54±11.94	36.44±11.69	34.70±9.41	0.90	0.56	0.80

[*] Chi-square test between affected and unaffected sides within patients
[a] Chi-square test between affected sides of patients and both sides of controls
[b] Chi-square test between unaffected sides of patients and both sides of controls

6.4 Comparison of anatomical parameters between males and females in Case group

No significant differences were shown in a comparison of all parameters between males and females within the Case group (all $p>0.05$; Table 4).

Table 4: Comparison of bony nasolacrimal duct measurements between males and females in the Case group

Parameters	Male (n=8)	Female (n=34)	p
BNLD length/mm	10.91±1.90	9.96±1.45	0.13
BNLD volume/mm^3	280.30±79.32	227.70±68.25	0.06
Angle of NLNF / °	89.85±1.79	89.84±2.46	0.99
Angle of Lacrimal sac-BNLD °	14.83±3.24	14.38±2.85	0.70
Area of proximal BNLD /mm^2	23.38±8.54	21.83±9.41	0.67
Minimum BNLD TD/mm	4.64±0.69	4.46±0.97	0.62

6.5 Comparison of BNLD measurements among different ages in Case group

A comparison of all parameters among different ages in the Case group failed to show any significant differences (all $p>0.05$; Table 5).

Table 5: Comparison of bony nasolacrimal duct measurements between different ages in the Case group

Parameters	20-40yrs(n=6)	40-60yrs(n=19)	60-90yrs(n=17)	P#	P##	P###
BNLD length/mm	9.96±1.29	9.83±1.52	10.55±1.69	0.98	0.71	0.36
BNLD volume/mm^3	269.2(186.4, 290.2)	228.8(189.3, 254.7)	221.3(171.6, 290.2)	>0.99	>0.99	>0.99
Angle of NLNF / °	89.15±1.30	90.24±2.99	89.64±1.69	0.59	0.90	0.72
Lacrimal sac-BNLD angle / °	13.05(11.00, 13.83)	14.10(12.20, 16.90)	14.20(13.45, 15.10)	0.42	0.20	>0.99
Area of proximal BNLD /mm^2	23.78±5.44	23.77±11.54	19.71±6.79	>0.99	0.62	0.39
Minimum BNLD TD/mm	4.35±0.70	4.66±1.02	4.36±0.88	0.76	>0.99	0.60
Area of minimum BNLD/mm^2	20.14±5.90	20.97±8.48	18.40±4.72	0.96	0.85	0.51
Area of distal end BNLD/mm2	38.83±17.18	40.21±12.10	34.11±9.30	0.97	0.68	0.28

[#] *Chi-square test between 20-40yrs and 40-60yrs in patients*
[##] *Chi-square test between 20-40yrs and 60-90yrs in patients*
[###] *Chi-square test between 40-60yrs and 60-90yrs in patients*

7. Conclusions

Structural abnormality of BNLD is considered a contributing factor to the occurrence of PANDO, which is characterized by tear flow resistance. The diagnosis and treatment depend on some invasive procedures such as transcanalicular laser therapy, balloon dilatation, and stent implantation. Consequently, it is important to learn the detailed morphology of BNLD before performing these invasive approaches[8].

CBCT or MDCT scans are helpful imaging tools for BNLD and aids the planning of surgery due to

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their remarkable ability to identify pathologies that affect the bony structures and the soft tissues of the nose and the paranasal sinuses[9]. Studies have concentrated on the concept that narrowing of BNLD might contribute to the occurrence of PANDO, since even minimal mucosal swelling in the narrow canal might result in obstruction of BNLD. Janssen et al[10]. compared PANDO patients treated with balloon dacryocystography and control subjects and found a statistical significance in mean minimum TD of BNLD, 3.0 mm (2 mm, 4.3 mm) in the patients and 3.5 mm (1.5 mm, 6.3 mm) in the control subjects. Therefore, the smaller TD of BNLD was supposed to be a predisposing factor for the occurrence of PANDO. A further study by Bulbul et al[11]. demonstrated significant differences between the patients and the control subjects in both affected and unaffected sides. However, other studies demonstrated no significant relationship between BNLD structure and PANDO occurrence. This is similar to our previous data and the results in this study.

Studies have also investigated the length of BNLD in normal subjects. Ramey et al[12]. reported lengths of (12.3 ±2.5) mm in men and (10.8 ±2.5) mm in women. Results from Bulbul et al. showed that the mean length of BNLD in PANDO patients was not significantly different from control subjects, which is consistent with the values of healthy subjects from Ramey et al[13]. In our study, there were no significant differences between the affected sides and unaffected sides within Case subjects, or between male and female subjects; however, the BNLD length was significantly longer in both the affected sides (10.14 ±1.57 mm) and the unaffected sides (9.92 ±1.48 mm) relative to the control sides (8.59 ±1.29 mm) (p<0.001 and p<0.001, respectively).

Other parameters evaluated in PANDO patients were the volume and the areas of proximal, minimum, and distal ends of BNLD. Estes et al[14]. recently demonstrated that the volume of BNLD in PANDO patients (411 ±18 mm^3) and control subjects (380 ±13 mm^3) did not differ significantly; however, women had smaller volume ducts (356 ±11 mm^3) than men (482 ±19 mm^3). A study from Bulbul et. al reported similarly. These align with our results that there was no statistical difference in the volume of BNLD between Case and Control subjects, or between affected and unaffected sides within Case subjects; women had shorter ducts, but there was no significant difference in volume (227.70 ±68.25 mm^3) compared of men (280.30 ±79.32 mm^3). The study from Bian et al. showed no statistical difference in the minimum area of BNLD in patients with nasolacrimal duct obstructive diseases using CBCT, while Mo et al. demonstrated no difference in the proximal and distal end areas of BNLD in patients with chronic dacryocystitis between the diseased eyes and normal eyes using CT. Consistent with this, our results showed no statistical difference in the volume or the areas of proximal, minimum, and distal end of BNLD among the affected, the unaffected sides and the control sides.

In addition, we wondered if there were any other parameters significantly associated with, and thus potentially predisposing factors for, PANDO. Interestingly, Samarei et al. studied the role of changes in sinonasal anatomical and paranasal inflammation in PANDO, and demonstrated that the occurrence of septal deviation was 3.037 times more frequent in the affected side than the unaffected side in PANDO patients. Therefore, the ipsilateral deviated nasal septum may also be a predisposing factor to the occurrence of unilateral PANDO. However, our results showed that the occurrence rates of deviated nasal septum were not significantly different among the affected, the unaffected sides and the control sides.

Moreover, Mo et al. studied the angle of NLNF in patients with obstructive diseases of the lacrimal duct and found that there were significant differences between diseased eyes relative to normal eyes in patients, as well as between diseased eyes in males and females; there was no difference among different ages. Similarly in our study, there was no difference among different ages; however, we demonstrated no significant difference between the affected sides and unaffected sides within patients. Furthermore, the NLNF angle was larger in both the affected sides and unaffected sides relative to the control sides, The difference between our study and Mo’s may be attributed to the number of subjects and the different imaging planes used for measurement.

Due to variations of inclination between the lacrimal fossa and the entrance of the BNLD, it is important to evaluate the BNLD type and the angle of relative lacrimal sac-BNLD in PANDO patients before non-surgical treatment to prevent complications. A Japanese cadaveric study demonstrated a mean relative angle of lacrimal sac-BNLD of 11.8 °(1–32 °) and no significant difference in the coronal type of BNLD between males and females. Bulbul et al. assessed the relative angle of lacrimal sac-BNLD in PANDO patients and normal controls and reported that there was no statistical difference among PANDO, non-PANDO, and control subjects. Mo et al. also evaluated this angle in patients with chronic dacryocystitis and demonstrated that there was a significant difference between the diseased eyes and normal eyes of female patients. Moreover, the angle in patients aged 41-60 years was larger than that in those aged 61-84 years. In our study, there were no significant differences between the affected and the unaffected sides, or males and females, or different ages within the Case group; however, the relative angle of lacrimal sac-BNLD was smaller in both the affected sides(13.95 mm; 12.68-15.10 mm) and the unaffected sides (14.05 mm; 12.88-15.53 mm) relative to the control sides (16.45 mm; 13.83-19.35 mm; p=0.02 and p=0.01, respectively). These conflicting results might be attributed to ethnicity and race differences in morphometric measurements, therefore more multicenter and comprehensive studies are needed to illustrate the matter going forward.

PANDO occurs more frequently in women. Studies have reported a narrower minimum BNLD TD in women among non-diseased subjects, and this was proposed to be a predisposing factor to PANDO development. However, results in PANDO patients showed conflicting results. In our study, all the parameters showed no gender difference in PANDO patients, suggesting that these parameters, regardless of patient gender, could be predisposing factors for PANDO.

PANDO usually occurs in women older than 40, implying that age may be a predisposing factor for PANDO. Mo et al. demonstrated that there were no significant differences in the cross-sectional area, length, inferior turbinate angle, and the angle of lacrimal sac-BNLD of the affected eyes at different ages. Similarly, we measured the angle of NLNF and the relative angle of lacrimal sac-BNLD and other anatomical parameters and observed that there were no significant differences among different ages in Case subjects. Our results revealed that these parameters regardless of age may be predisposing factors for PANDO.

Our study revealed a significant difference in the BNLD length in Case subjects relative to Control subjects, in both the affected and unaffected sides. This implies that longer BNLD may be a factor for PANDO occurrence. Additionally, the larger angle of NLNF and the smaller relative angle of lacrimal sac-BNLD in the Case subjects relative to the Control subjects, both in the affected and unaffected sides of patients, may augment the studies on predisposing factors for PANDO. However, the lack of difference between the affected and unaffected sides of Case subjects and some overlap between Case and Control subjects indicates that these are not the sole factors. More multicenter studies with greater numbers of subjects are needed in the future to learn more.

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JL and LO collected and analyzed the data and wrote the manuscript. LJ revised the manuscript. All the authors contributed to the article and approved the submitted version.

The study has been evaluated by the hospital ethics committee: PLA general hospital ethics committee and deemed not to require ethics approval.

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