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ORIGINAL PAPER

Three-dimensional semi-autotamatic segmentation of nasolacrimal duct morphometry on computed tomography images

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Abstract
Purpose Given the potential role of nasolacrimal duct (NLD) morphometry in the aetiology of primary acquired obstructions, it is imperative that clinicians have access to detailed anatomical information. The aim of this study was to determine normative data on nasolacrimal duct morphometry in the Turkish population sample and to provide guidelines for clinicians.
Methods The study included retrospectively computed tomography images of a healthy Turkish population sample of 151 individuals, 79 of whom were female and 72 of whom were male. Images were modeled and analyzed using 3D Slicer version 5.2.2.
Results The total volume and area of the NLD were smaller in females than in males. The right- and left-sided volume of the NLD were smaller in females than in males (In male, right side 219.28 ± 77.53 mm^3 and left side 213.14 ± 73.82 mm^3; in female, right side 193.82 ± 75.71 mm^3, left side, 190.34 ± 82.54 mm^3). Although the anteroposterior and transverse diameters of the right-sided NLD were not statistically different between the genders, the anteroposterior and transverse diameters of the left-sided NLD and distance between right and left NLD were smaller in female than in males. The volume and surface area of the right-sided NLD and the distance between the right and left NLD were larger with increasing age. The anteroposterior diameter was observed to be larger on the right side than on the left in both sexes, whereas the transverse diameter was larger on the right side than on the left side exclusively in females.
Conclusion The results of this study may assist clinicians in the surgical approaches.

Keywords Three-dimensional reconstruction · 3D Slicer · Morphometry · Nasolacrimal duct

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Introduction

The nasolacrimal duct (NLD) is a tubular part of the lacrimal apparatus. The lacrimal apparatus comprises the lacrimal gland, punctae, canaliculi, lacrimal sac, and nasolacrimal duct. The nasolacrimal duct collects tear fluid from the surface of the eye and carries it into the nasal cavity [1, 2]. The NLD is divided into two parts: the upper part in the lacrimal sac and the lower part in the nasolacrimal canal. The nasolacrimal canal is formed by the articulations between the lacrimal groove of the maxilla, the descending process of the lacrimal bone and the lacrimal process of the inferior concha. The middle section of the nasolacrimal canal is narrower than its two ends. The nasolacrimal duct runs along inferolaterally and posteriorly the lateral wall of the nasal cavity and enters the inferior nasal meatus behind the anterior end of the inferior nasal concha. The NLD is approximately 12–18 mm in length and opens into the inferior nasal meatus through a mucosal fold known as plica lacrimalis (Hassner's valve) [3, 4].

The lacrimal drainage system, in which NLD plays a major role, can be affected by various pathological processes such as inflammation, abscess formation, tumor infiltration or traumatic injuries. All these processes cause obstruction. Obstruction often manifests as watery eyes, also known as epiphora, and is a common clinical sign [5, 6]. Nasolacrimal duct obstruction, also known as dacryostenosis, may be congenital or acquired [7] Acquired nasolacrimal duct obstruction is classified as either primary or secondary based on its underlying cause. Secondary acquired nasolacrimal duct obstruction can be caused by conditions such as neoplasm, trauma, or sarcoidosis. The etiology of primary acquired nasolacrimal duct obstruction (PANDO) remains unclear. In recent years, it has been argued that a narrow nasolacrimal duct may be a key factor for PANDO. Ali et al. stated that NLD anatomy is imperative to understand the pathophysiology of PANDO [8].

Minimally invasive procedures, such as endoscopy, laser therapy, stent implantation, and balloon dilatation, are used to diagnose and treat lacrimal drainage system obstructions. It is essential that the equipment used during these procedures is fully compatible with the anatomical structures. Detailed anatomical and morphometric information is necessary for this reason [9–11].

The nasolacrimal duct has been studied in patient and healthy groups, often with two-dimensional evaluations in radiological images, cadavers or autopsy specimens. These evaluations are inadequate for the normal dimensions and shape changes of NLD. Very few studies have focused on the three-dimensional examination of NLD. Ali et al. noted the adjacent anatomy of the lacrimal sac and nasolacrimal duct and stated that detailed anatomical definitions are required to understand PANDO [12] Detailed anatomical information about the NLD elucidates the etiology of the obstruction and assists the clinician in determining an effective treatment or minimally invasive approach [13–16]

According to studies in the literature, the morphometry of the nasolacrimal duct may vary according to race, age and gender [17]. The aim of this study is to investigate the morphometry of the nasolacrimal duct with two and three dimensions in the Turkish population sample using computed tomography and to determine the anatomical differences between the sexes. To this end, it is intended to fully define the morphometry of the nasolacrimal duct, to present social normative data to the literature, and to provide evidence to guide clinicians.

Materials and methods

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University (22.06.23/548). A total of 151 Turkish subjects, 79 female and 72 male, aged 20 to 95 years, were included in the study. In order to evaluate the differences of the parameters between age groups, the participants were divided into three groups as 20–44, 45–69 and 70–95 age groups. Computed tomography (CT) scans of the skull were reviewed retrospectively. Participants with a history of trauma, neoplasm, bone disease or interventional procedures involving the orbit, nose or paranasal sinuses, and cases with reported pathologies affecting the nasolacrimal system (e.g., sinusitis, severely deviated septum) were excluded from the study.

Radiological examination protocol and measurements

CT scans were performed without contrast using a 256 multidetector CT (MDCT) scanner (Philips Brilliance iCT, Philips Medical Systems, The Netherlands). CT images of the skull were imported into 3D Slicer version 5.2.2. The data were imported into the 3D Slicer program in DICOM format. In the horizontal plane view, “Line” was selected from the “Markup” tab and the anteroposterior and transverse diameters of the right and left NLD were measured at the widest point. The distance between the most medial points of the right and left NLD was measured. The measurement of the parameters is shown in Fig. 1. After the measurements were recorded, they were deleted with "Delete Line". The segmentation process was then started using the Segment Editor tab. “Drawl” was selected and the canal was stained from the uppermost segment, where the contour of the NLD bone is visible, to the level of the inferior nasal meatus, which is the lowest segment. After the segmentation process, the 2D image was reconstructed as 3D by pressing the “Show 3D” button. The volume, surface area and number of voxels of the resulting 3D structure were calculated with "Segment Statistics".

Statistical analysis

Data analysis of the study was performed using the Statistical Package for Social Sciences (SPSS) version 20.0 (SPSS inc., Chicago, IL, USA). The distribution of data in both groups was determined by the Kolmogorov–Smirnov test. All parameters showed normal distribution except the volume, area, anteroposterior and transverse diameter of the left NLD. For comparison between sexes, the independent samples t-test was used for normally distributed data and the Mann–Whitney U test for abnormally distributed data. Correlation analysis was performed using Pearson’s correlation tests for normally distributed data and Spearman’s correlation tests for abnormally distributed data. When comparing the right and left sides of dependent variables, the paired sample t-test was used for normally distributed data and the Wilcoxon test for abnormally distributed data. Anova analysis was used for the analysis between age groups. Data are presented as mean and standard deviation (mean ± SD), and a probability value of $p < 0.05$ was considered significant.

Results

A total of 151 people, 47.7% male (n = 72) and 52.3% female (n = 79), were included in the study. A total of 302 NLDs were measured on both the right and

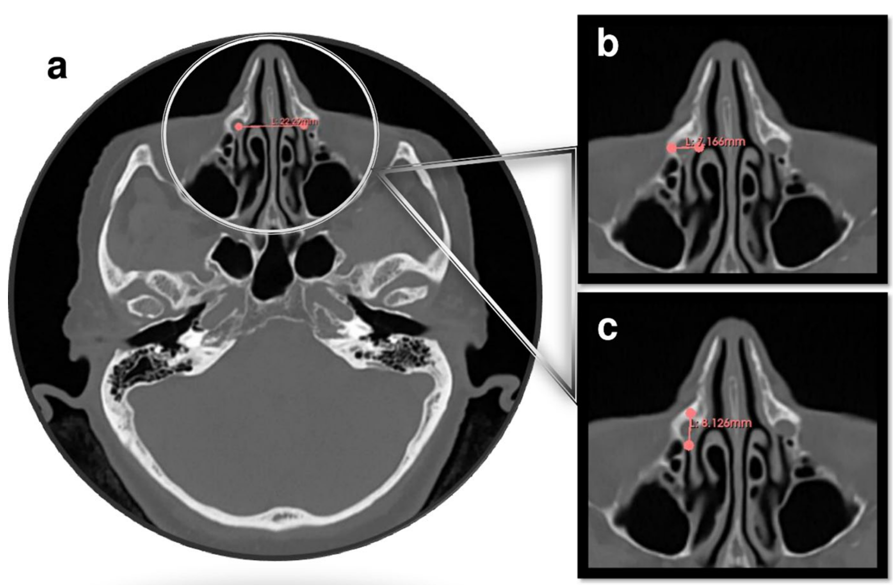

Fig. 1 Radiological measurement image of the distance between both NLDs, anteroposterior diameter, transverse diameter parameters. **a**: Image of the distance between both NLDs, **b**: Image of the anteroposterior diameter measurement in the right NLD, **c**: Image of the transverse diameter measurement in the right NLD

left sides of all participants. The mean age of the females was 51.37 ± 20.51 (age range: 21–95) and the mean age of the males was 54.93 ± 18.46 (age range: 20–88).

The nasolacrimal duct was reconstructed from two-dimensional to three-dimensional and the parameters were evaluated. The three-dimensional nasolacrimal duct model is shown in Fig. 2.

In the right, left and total volumes, surface area, left anteroposterior and left transverse diameter, the distance between right and left NLD measurements were statistically significantly lower in females compared to males. The right anteroposterior and the right transverse diameter measurements of NLD were lower in females compared to males, but there was no statistically significant difference. Table 1 shows the means, standard deviations and p-values between the genders.

The right and left sides of the dependent samples were compared in the female and male groups. In both female and male groups, the right side was statistically significantly larger than the left side in the anteroposterior diameter measurements of the NLD. The anteroposterior diameter of the NLD showed a highly positive correlation between the right and left sides in the female group, while it showed a moderate positive correlation in the male group ($p = 0.001$ for both gender group; $r = 0.801$ for female group; $r = 0.660$ for male group). In the female group, the right side was statistically significantly larger than the left side in the transverse diameter measurements of the NLD, and this parameter showed a moderate positive correlation between the right and left sides ($p = 0.045$, $r = 0.625$). This results are shown in Fig. 3. There was no statistically significant difference in other parameters on the right and left sides.

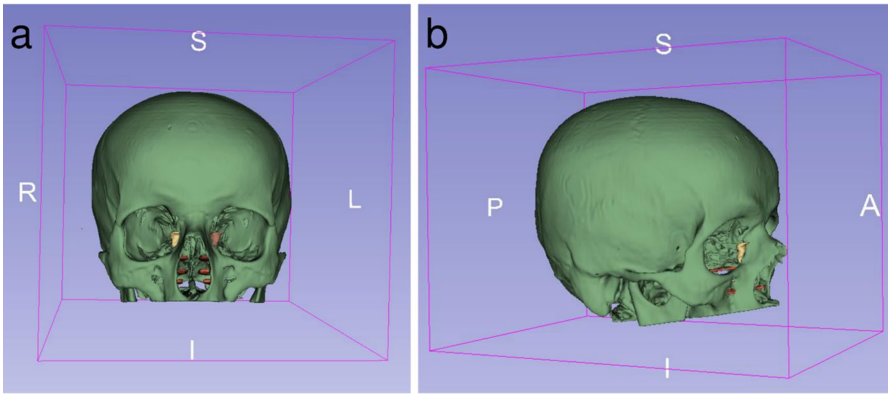

Fig. 2 Demonstration of three-dimensional reconstruction of the NLD in the skull. **a**: Front view, right NLD is depicted in yellow and left NLD is depicted in brown, **b**: Lateral view, right NLD is depicted in yellow

Table 1 Comparison of parameters between male and female genders

Parameters	Female (n = 79)		Male (n = 72)		P value
	Mean	Standart deviation	Mean	Standart deviation	
Total volume (m^3) (n = 158 in females, n = 144 in males)	192.08	78.97	216.21	75.50	0.043*
Right volume (m^3)	193.82	75.71	219.28	77.53	0.025*
Left volume (m^3)	190.34	82.54	213.14	73.82	0.007*
Right area (m^2)	191.25	56.58	214.02	59.10	0.017*
Left area (m^2)	190.73	56.75	208.82	53.98	0.034*
Right anteroposterior diameter (mm)	9.47	1.64	9.87	1.55	0.054
Left anteroposterior diameter (mm)	8.80	1.62	9.27	1.51	0.016*
Right transverse diameter (mm)	8.02	1.20	8.14	1.30	0.453
Left transeverse diameter (mm)	7.78	1.37	8.30	1.37	0.018*
Distance between right and left side (mm)	25.80	2.72	26.75	2.82	0.038*

* P-values of less than 0.05 are considered statistically significant

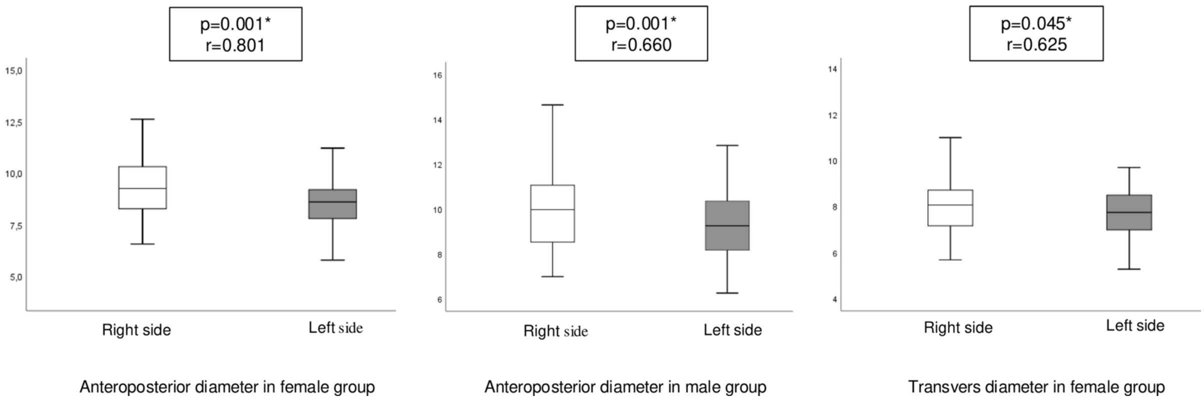

Fig. 3 Comparison and correlation of right and left side dependent samples

All parameters were evaluated in three consecutive increasing age groups. There were 60, 57 and 34 subjects in the 20–44, 45–69 and 70–95 age groups, respectively. The right NLD volume, surface area and distance between right and left NLD were statistically significant between age groups ($p=0.012$, $p=0.017$, $p=0.001$, respectively). The mean ± SD values of these three parameters were higher in increasing age groups and are shown in Fig. 4.

The correlation matrix of the parameters is shown in Table 2. There was a statistically significant positive high correlation between both the right-side NLD volume and area and the left-side NLD volume and area ($r=0.960$, $r=0.965$, $p=0.000$ respectively). There was a statistically significant moderate correlation between the volume, area, anteroposterior and transverse diameters of the NLD between the left and right sides ($r=0.626$, $r=0.626$, $r=0.743$, $r=0.651$, $p=0.000$, respectively).

Discussion

The shape and morphometric characteristics of the nasolacrimal duct are important in the etiology of obstruction. NLD obstruction is the most commonly reported problem of the lacrimal drainage system. It has also been reported that early diagnosis of ductal obstruction by the clinician can prevent epiphora [5, 18] Endoscopic procedures are preferred in PANDO surgery because they are more advantageous than standard methods. In these applications, the complex anatomical structure of NLD can cause irreversible damage to the structures containing the lacrimal apparatus, including extensive muscle injury, tissue loss and bleeding. For these reasons, recognising the morphological structure of NLD and fully understanding and predicting its variations is very important for surgical success [19].

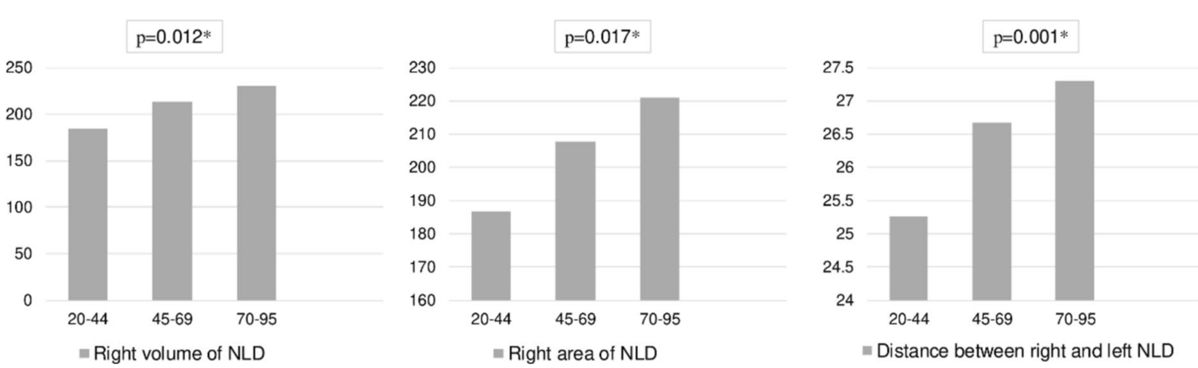

Fig. 4 Comparison of parameters between age groups

Table 2 R values in the correlation matrix of the parameters for all participants (n = 151)

	Right-side volume	Right-side area	Right-sided anteroposterior diameter	Right-sided transverse diameter	Left-side volume	Left-side area	Left-sided anteroposterior diameter	Left-sided transverse diameter
Right-side volume	1							
Right-side area	0.960*	1						
Right-sided anteroposterior diameter	0.438*	0.368*	1					
Right-sided transverse diameter	0.382*	0.340*	0.536*	1				
Left-side volume	0.626*	0.587*	0.443*	0.352*	1			
Left-side area	0.629*	0.626*	0.381*	0.290*	0.965*	1		
Left-sided anteroposterior diameter	0.421*	0.373*	0.743*	0.591*	0.472*	0.395*	1	
Left-sided transverse diameter	0.364*	0.336*	0.592*	0.651*	0.400*	0.309*	0.647*	1

* P-values of less than 0.05 are considered statistically significant

r > 0.750 indicated high correlation, r = 0.50–0.75 moderate correlation, r < 0.500 low correlatio

Because of the clinical importance of knowing the variation in NLD by race or ethnic group, age and sex, this issue is being investigated further [17]. Lin et al. conducted a study which found that the NLD is longer in Oriental and Afro-Caribbean groups compared to European and South Asian groups [15]. Ramey et al. found that the cross-sectional area of the canal base was larger in black patients than in white patients [20]. Another study reported that there was no significant difference in the average diameter of NLD between Caucasian and New Zealand Maori populations, while it was larger in Pacific People [21]. In this study, we selected 151 participants from the Turkish population. To our knowledge, this is the first study to investigate NLD morphometric features with a high sample size in this population. Our findings were similar to studies conducted in Caucasians rather than Blacks.

According to Ramey et al., the canal cross-sectional diameter was larger in patients over 50 years of age compared to younger patients. [20]. Lin et al. demonstrated a positive correlation between age and the diameter of the nasolacrimal duct [22]. In a study of 286 female and 185 male aged 16–86 in a Black African population, individuals were divided into eight groups based on age range. The study found no significant difference in NLD canal diameter between the age groups [23]. The differences between age groups in all parameters in our study were examined. The volume and surface area of the right-side NLD and the distance between right-left side NLD showed significant differences between age groups, and these parameters increased in direct proportion to age ($p = 0.012$, $p = 0.017$, $p = 0.001$, respectively). However, this issue is controversial because anthropometric differences such as gender are not distributed homogeneously in all study groups evaluating NLD according to age groups. In order to assert with a high degree of certainty that the NLD increases with age, it is necessary to evaluate large sample groups comprising separate groups of male and female.

Lin et al. found that the nasolacrimal duct tends to be longer in males than in females [22]. In the study by Ercakmak et al., which included 65 females and 77 males, the mean antero-posterior diameter of the right NLD was 4.67 ± 0.12 mm in females and 5.09 ± 0.13 mm in males, while the mean antero-posterior diameter of the left NLD was 4.67 ± 0.12 in females and 4.95 ± 0.1 mm in males. The study found that the transverse mean diameter of the right NLD was 3.81 ± 0.08 in females and 4.2 ± 0.09 mm in males, while the transverse mean diameter of the left NLD was 3.74 ± 0.09 mm in females and 4.15 ± 0.09 mm in males. However, no statistically significant differences were reported in any morphometric parameter [24]. In this study, we found that the anteroposterior and transverse diameters of the left nasolacrimal duct were significantly larger in males than in females ($p = 0.016$, $p = 0.018$, respectively). However, there was no significant difference in the right anteroposterior and transverse diameters of the NLD between males and females, which is consistent with the findings of Ercakmak et al. While this may appear to be statistically insignificant, a potential explanation may lie in the morphometrically larger skulls observed in males in comparison to females. To achieve statistically significant results, it is imperative to analyse larger sample groups with homogeneous gender distribution.

It is hypothesised that the evaluation of the three-dimensional volume of the NLD, as an alternative to its diameters, is a more significant metric for the discernment of differences between the genders. Lee et al. conducted a study on 63 males and 55 females and found that the right NLD volume was 401.5 ± 192.6 m^3 in males and 360.5 ± 155.9 m^3 in females, while the left NLD volume was 359.9 ± 170.9 m^3 in males and 351.7 ± 146.3 m^3 in females. However, there was no statistically significant difference between the genders [19]. In our study included 72 males and 79 females, and found that the right NLD volume was 219.28 ± 77.53 m^3 in males and 193.82 ± 75.71 m^3 in females, while the left NLD volume was 213.14 ± 73.82 m^3 in males and 190.34 ± 82.54 m^3 in females. Both right and left NLD volumes were statistically significantly greater in males than in females ($p = 0.043$ for right NLD, $p = 0.025$ for left NLD). In these studies, in which right and left-sided NLD were evaluated separately with regard to the potential presence of facial asymmetry, the larger findings in males in comparison to females are unsurprising. These findings may provide clinicians with a framework for surgical interventions that can be performed from either the right or left side. Nevertheless, the findings of a study conducted in Korea, which did not make distinctions between the right and left side, presented to the literature that males (265.33 ± 90.57 mm3) have a larger NLD volume than females(211.87 ± 68.61 mm3) [25]. In the course of undertaking 302 NLDs within the scope of this study, it was confirmed that the NLD volume is larger in males (214.82 ± 73.57 mm3) than in females (196.58 ± 78.19 mm3) when considered across the larger sample group.

The most significant finding of this study was the examination of NLD measurements of the right and left sides of the same subject, with comparisons being made in dependent variables. The anteroposterior diameter of the NLD was significantly larger on the right side in both the male ($n = 72$) and female groups ($n = 79$), and the transverse diameter of the NLD was larger on the right side than on the left side in the female group. A study conducted in a Nepalese population emphasized that the anteroposterior diameter of the right sided NLD was larger than the left sided NLD, similar to our findings [26]. Another study focusing on the length of the NLD showed that the right side was slightly longer than the left side [27]. The findings reported in the extant literature, in addition to those derived from the present study, provide compelling evidence to support the hypothesis of facial asymmetry. However, further detailed research, incorporating a rigorous examination of embryology, is required to provide a definitive explanation for the observed discrepancy in size between the right and left sides. In fact, a number of cadaveric studies have reported that the dimensions of the nasolacrimal duct are equivalent on the right and left sides, with no statistical discrepancy; a finding that would be inconsistent with the present hypothesis [28, 29].

There are several limitations to this study. First, this study is based on a retrospective analysis, meaning that our findings include analysis of available medical records and imaging data. Since we obtained images from a single hospital, the sample we included in the study was limited in reflecting the Turkish population. Furthermore, although our sample size is relatively adequate, it only includes a specific subset of the Turkish population.

Conclusion

The present study offers a comprehensive analysis of the normal morphometric features of the nasolacrimal duct in the Turkish population sample. As a result of the study, the mean volume of NLD was determined to be 192.08 ± 78.97 cm3 for females and 216.21 ± 75.50 cm3 for males. The area and volume of the right-sided NLD, the area, volume, anteroposterior and transverse diameter of the left-sided NLD, and the distance between the right and left NLD were lower in females. The anteroposterior diameter in both sex groups and transverse diameter in the female group were smaller on the left side than on the right. Upon analysis of age groups, it was found that the area and volume of the right NLD and the distance between the right and left NLD increased with age. These knowledges can assist in understanding the clinical background of obstructions. and contribute to the establishment of morphometric basic standards. This can contribute to a precise planning of interventions and a full compliance with the anatomical features of the NLD during the use of surgical technical equipment.

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Author contributions All authors contributed to the study conception and design. The project development was undertaken by Bahar Tekin. Kadriye Betül Pence conducted a review of the literature, expanded the project, and drafted the manuscript. Tuğrul Ormeci collected data and determined radiological measurements from a radiologist's point of view. Nureda Nalcaci Bozkurt was responsible for data collection and analysis. The analysis of the study's statistical data was performed by Selva Sen. Gamze Ansen and Neslihan Yuzbasioglu edited the manuscript and the figures/tables. Neslihan Yuzbasioglu was also the supervisor of this study. All authors read and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University (22.06.23/548).

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent to publish The authors affirm that human research participants provided informed consent for publication of the images in Fig. 1.

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