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3-D Volumetric Assessment of the Nasolacrimal Duct in Patients with Obstruction

Jaclyn L Estes¹, Apostolos J Tsiouris, M.D.², Paul J Christos, Dr.P.H., M.S.³, and Gary J Lelli, M.D.⁴

¹Weill Cornell Medical College

²The Department of Radiology at Weill Cornell Medical College and NewYork-Presbyterian Hospital

³The Department of Public Health at Weill Cornell Medical College

⁴The Department of Ophthalmology at Weill Cornell Medical College and NewYork-Presbyterian Hospital

Abstract

Purpose—The purpose of this study was to determine if a significant difference exists in the nasolacrimal duct volume of subjects with primary nasolacrimal duct obstruction (PNLDO) compared with controls.

Methods—This was a retrospective, case-controlled study of 70 subjects with prior maxillofacial CT scans, including 35 subjects with obstruction and 35 controls. Volume measurements of the nasolacrimal duct were made on a GE Advantage Workstation using volume viewer software, and measurements compared using an unpaired student t-test. Inter-rater and intra-rater reliability were calculated.

Results—There was no significant difference between the nasolacrimal duct volume in patients ($0.411 \pm 0.18 \text{ cm}^3$) compared with controls ($0.380 \pm 0.13 \text{ cm}^3$), $p=0.23$. Women had smaller volume ducts ($0.356 \pm 0.11 \text{ cm}^3$) than men ($0.482 \pm 0.19 \text{ cm}^3$), $p<0.001$. Male patients had smaller volume ducts ($0.470 \pm 0.23 \text{ cm}^3$) than male controls ($0.493 \pm 0.14 \text{ cm}^3$), $p=0.70$, while female patients ($0.384 \pm 0.13 \text{ cm}^3$) had significantly larger volume ducts than female controls ($0.328 \pm 0.08 \text{ cm}^3$), $p=0.01$. There was excellent inter- and intra-rater reliability.

Conclusions—CT 3-D volumetric software can be used to accurately measure the nasolacrimal duct volume in patients with obstruction. Both the absence of a significant difference between patient and control nasolacrimal duct volumes plus the overlap in range between the two groups imply that the volume of the tear duct is likely not related to the etiology of obstruction. The

Address correspondence and reprint requests to Gary J. Lelli, M.D., Weill Cornell Medical College, 1305 York Ave, 12th Floor, New York, NY 10065. GJL9003@med.cornell.edu.

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increase in volume seen in females with obstruction may be due to expansion of the bony canal during the post-menopausal years. The exact etiology of PNLDO requires further investigation.

Introduction

Nasolacrimal duct obstruction can be classified as congenital or acquired, with the latter typically affecting adults over age 50 and women more commonly than men.¹ The majority of nasolacrimal duct obstruction cases are idiopathic (primary nasolacrimal duct obstruction, PNLDO) and a small number of cases are secondary to a known cause (e.g. neoplasm, trauma, surgery, or sarcoidosis).² In both subtypes, patients present with epiphora and/or dacryocystitis. Many cases require surgical repair via dacryocystorhinostomy.³ The etiology of PNLDO remains in question. Prior studies have examined the minimum diameter of the nasolacrimal duct on axial CT and found that women have smaller diameters than men, which was proposed as one possible etiology for PNLDO due to the higher incidence in women.^{4,5,6,7,8} In other association studies, researchers have found that populations that tend to have a higher prevalence of PNLDO actually have larger minimum diameters, implying that a large diameter may be an effect rather than a cause of PNLDO.^{9,10} The discrepancy is in part due to the difficulty making a two dimensional measurement of a three dimensional space since the minimum diameter varies depending on the plane of the image. Only one study has examined the three dimensional characteristics of the nasolacrimal duct in normal subjects, but found no difference in the diameter or volume between groups of varying age, gender, or race.¹¹ Few studies have directly compared the nasolacrimal duct anatomy of adult patients with and without obstruction.^{8,12}

The purpose of this study was to determine the volume of the nasolacrimal duct in patients with obstruction compared to controls using CT images and 3D volume reconstruction software. The authors hypothesized that patients with obstruction would have smaller volumes than control subjects in keeping with the more widely-held belief that PNLDO is caused by a smaller nasolacrimal duct.

Materials and Methods

Subjects

This was a retrospective, case-controlled study of 70 subjects, including 35 patients and 35 controls. Our Institutional Review Board approved this study. All subjects were seen and treated from 2008 to 2013 for primary nasolacrimal duct obstruction (PNLDO) at NewYork-Presbyterian Hospital – Weill Cornell Medical Center (NYPH-WCMC). All included subjects had a CT scan of the maxillofacial structures after the diagnosis of PNLDO but prior to the start of the study as a pre-operative evaluation for surgery. Subjects and controls were all over age 60 at the time of imaging to test the hypothesis that the volume of the bony canal of the nasolacrimal duct narrows in patients with PNLDO. A total of 35 patients in the population met these inclusion criteria, and 35 controls were selected from a randomly-created list of patients treated in the Emergency Department at the same institution. Control subjects were chosen from patients imaged for facial trauma or inflammatory sinus disease and had no history or imaging evidence of nasolacrimal pathology; additionally they were matched to the patient population by age, gender, and CT slice thickness.

Volume Measurements

The subjects and controls were randomized prior to taking measurements. The side of obstruction was recorded for the patient group as OD (right eye), OS (left), or OU (both). All scans were acquired prior to the study on either 16 or 64 detector helical GE CT scanners (General Electric, Milwaukee, WI) with slices acquired in the axial plane and reconstructed in the sagittal and coronal planes. Patient and control groups were matched by slice thickness, with 13 scans (37%) in each group having a voxel size of 0.29 x 0.29 x 0.625 mm and 22 scans (63%) in each group having a voxel size of 0.29 x 0.29 x 1.25 mm. All images included the orbit and had a 120-kVp tube voltage, a field of view ranging from 15 to 23 cm, and a tube current ranging from 140 to 289 mA. A commercially-available GE Advantage Workstation version 4.2_04 with 3D volume viewer software was used to analyze the nasolacrimal duct and determine volumetric data, which was analyzed by a single reviewer (JLE) and confirmed by an attending neuroradiologist (AJT). Using the software paintbrush tool, the lumen of the osseous nasolacrimal duct was first selected on axial images and then confirmed on sagittal and coronal reformations (Fig. 1). Superiorly, the boundary of the nasolacrimal duct was defined as the entry of the lacrimal sac into the bony canal at the junction between the frontal process of the maxilla and the lacrimal bone, and inferiorly as the outflow of the duct into the inferior meatus at the valve of Hasner. The volume was then computed by the software of the GE Advantage Workstation and recorded (Fig. 1). Volume measurements were made by a blinded reviewer for each duct, three times, non-consecutively, and the averages calculated.

Statistical Methods

Measurements between subjects and controls were compared using an unpaired student t-test to determine the significance of any differences. All p-values are two-sided with statistical significance evaluated at the 0.05 alpha level. Intra-rater (i.e., test-retest) reliability, which measures the precision of repeated measurements for a single reviewer, was assessed by the Pearson correlation coefficient. For both eyes, each of the three sets of measurements was compared with one another. To test inter-rater (i.e., inter-observer) reliability, both the primary reviewer and an attending neuroradiologist with 10 years of experience and a certificate of added qualification (CAQ) in neuroradiology made volume measurements on a random sample of 13 subjects (26 ducts). This was assessed by the intraclass correlation coefficient (ICC) using a two-way random effects model, which assumes that observers are randomly sampled from a pool of observers and patients [i.e., eyes] are randomly sampled from a pool of patients. All analyses were performed in SPSS Version 21.0 (SPSS Inc., Chicago, IL).

Results

Subjects

The study included 35 patients and 35 controls, with 24 women (69%) and 11 men (31%) in each group. In the patient group, the mean age and standard deviation were 71.3±8.5, closely matching the age distribution of the control group of 71.1±7.8.

Volume Measurements

All data are presented in Table 1. There was no significant difference between the nasolacrimal duct volume in patients ($0.411 \pm 0.18 \text{ cm}^3$) compared with controls ($0.380 \pm 0.13 \text{ cm}^3$), $p=0.23$, 95% CI, $-0.04 - 0.10 \text{ cm}^3$. In fact, the shape of the confidence interval suggests mean differences that are more consistent with smaller average volumes for control patients. The mean volume for patients had a right skew when compared with controls, as shown in Figure 2. No difference existed between the right and left eyes for either patients or controls. Overall, women had significantly smaller volume ducts ($0.356 \pm 0.11 \text{ cm}^3$) than men ($0.482 \pm 0.19 \text{ cm}^3$) when patient and control volumes were merged, $p < 0.001$. Male patients had smaller volume ducts ($0.470 \pm 0.23 \text{ cm}^3$) than male controls ($0.493 \pm 0.14 \text{ cm}^3$), reversing the overall trend seen in patients compared with controls, but this finding was not significant ($p=0.70$). Conversely, female patients had larger volume ducts ($0.384 \pm 0.13 \text{ cm}^3$) than female controls ($0.328 \pm 0.08 \text{ cm}^3$), a statistically significant finding ($p=0.01$). The average duct volume in male controls was 51% larger than in female controls ($p < 0.0001$), but in male patients was only 22% larger than in female patients ($p=0.13$). Patients had a much smaller difference between mean volumes and larger standard deviations in both males and females, indicating wider distributions.

Inter-rater and Intra-rater Reliability Analyses

The intraclass correlation coefficient (ICC) was 0.93 (95% CI = 0.81, 0.97) ($p < 0.0001$), which implies excellent inter-rater reliability between the primary reviewer and the experienced neuroradiologist. The intra-rater (test-retest) reliability was also excellent, with the Pearson correlation coefficient greater than 0.90 for each comparison, significant at the 0.01 level (2-tailed).

Discussion

This study confirmed that 3D volumetric software can be used to accurately measure the volume of the nasolacrimal duct in patients with obstruction. The voxel size of the scans was $0.29 \times 0.29 \times 0.625 \text{ mm}$ in 26/70 subjects and $0.29 \times 0.29 \times 1.25 \text{ mm}$ in 44/70 subjects, providing for accurate resolution of the relatively small nasolacrimal duct. We discovered several interesting trends, the first of which was that female patients had significantly larger volume ducts than female controls, a trend that was not present in males. This was unexpected based on the hypothesis that smaller-volume tear ducts cause primary nasolacrimal duct obstruction, which numerous other studies suggest.⁸ We postulate that volume paradoxically increased in female cases secondary to a focal area of stenosis followed by dacryocystocele formation and bony remodeling. Other factors have been noted to potentiate PNLDO, including inflammation, mucosal epithelial changes, soft tissue changes and hormonal irregularities.^{5, 9, 13, 14, 15}

There was no significant difference in volumes between cases and controls, and both groups had similar ranges of values. The overlapping nature of the tear duct volumes implies that a smaller tear duct volume does not predispose someone to develop PNLDO. While not significant, patients overall had larger volumes than controls, which was also found by association in other studies.^{9,10} In one, researchers found that Nigerians had smaller

diameter canals than Caucasians and Asians even though they had a lower prevalence of PNLDO.¹⁰ In the other, Pacific People had larger diameters than Caucasian and New Zealand Maori, despite a higher incidence of dacryocystorhinostomy.⁹ While these studies did not measure diameters in obstructed patients and only relied on association, it seems that volume cannot be considered a predictor of this disease.

There was no significant difference between obstructed and non-obstructed nasolacrimal ducts in the patient group. All three of these subsets had larger volumes than the control group, following the general trend of patients having larger volumes than controls.

Figure 2 demonstrates a right skew in the volumes of nasolacrimal ducts for patients when compared with controls, which accounts for the observed larger mean volume seen in patients, however this finding was not significant. The final notable finding was that males had larger volumes than females in both cases and controls, but that the difference between the two was diminished in the patient group. These data confirm what other studies have shown: that in normal subjects women tend to have smaller anatomy. However, there may be a process that reduces the difference between men and women during obstruction. Expansion of the bony canal may occur as a result of chronic inflammation and high pressure within the canal, which could have a greater effect on women due to their bone composition after menopause. We propose therefore that the larger volumes seen in cases compared with controls may actually be an outcome of PNLDO instead of a possible etiology, and that the higher incidence in women may have more to do with their higher tendency for bony remodeling in their later years.

The authors acknowledge several limitations in the current study. The age range of subjects in the study was narrow and focused on older adults with obstruction. Studies have shown that the bony structures in the face change with time,¹⁶ and future studies should include subjects from a broader age range. This was a retrospective study where the control population was distinct from the patient population; an ideal study would be longitudinal and have each patient serve as their own control to determine who develops obstruction and who does not. No formal power calculation was performed prior to the start of the study; rather the sample size was based on the total number of patients who met the nasal obstruction criteria listed above for the defined time period, with an identical number of controls selected for comparative purposes. However, there is actually a non-significant trend ($p=0.23$) that is suggestive of a smaller average volume for controls as compared to cases. It is therefore unlikely that this trend would reverse in favor of the original hypothesis even with a larger sample size. This was a small pilot study intended to estimate mean volume for the available case group and the control group, and a larger study is required to confirm these null findings. Race was not a controlled variable and could be a potential confounding factor, since prior studies have demonstrated differences in duct volumes that varied by race;^{10,11} future studies should consider race as a separate variable when comparing volumes. This study only considered the bony canal of the nasolacrimal duct and not the soft tissue, which is cited as a site of inflammation and possible etiology of obstruction.¹⁷ Finally only one author (JLE) made volume measurements which were validated by a more experienced neuroradiologist (AJT).

To the authors' knowledge, only one other study has been completed which utilized volumetric software to study the nasolacrimal duct, but that study was limited to normal subjects.¹¹ Herein, we report use of this software on patients with PNLDO and compare them to a normal, control group. The findings suggest that the volume of the nasolacrimal duct is not related to PNLDO.

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Figure 1.

Demarcation of the nasolacrimal duct lumen volume on axial CT images using the GE-AW paintbrush tool (A). The duct boundaries were confirmed on coronal (B) and sagittal (C) views. Volume was computed using the commercially available GE-AW volumetric software package (D).

Figure 2.
Distribution of the nasolacrimal duct volumes in patients and controls.

Table 1

Demographics and Mean Volume Measurements of Nasolacrimal Ducts in Patients and Controls

	Patients (cm ³) [range]	Controls (cm ³) [range]	Significance: p value
Age (mean)	71.3±8.5 [60–93]	71.1±7.8 [60–88]	0.93
Both Eyes	0.411±0.18 [0.174–1.052]	0.380±0.13 [0.207–0.798]	0.23
Right Eye	0.418±0.18 [0.197–1.052]	0.377±0.11 [0.222–0.710]	0.27
Left Eye	0.405±0.17 [0.174–0.934]	0.383±0.14 [0.207–0.798]	0.56
Males	0.470±0.23 [0.200–1.052]	0.493±0.14 [0.317–0.798]	0.70
Females	0.384±0.13 [0.174–0.796]	0.328±0.08 [0.207–0.501]	0.01
Significance	p=0.13	p<0.0001	
Males-All	0.482±0.19 [0.200–1.052]		
Females-All	0.356±0.11 [0.174–0.796]		<0.001
Obstructed Eye	0.407±0.19 [0.174–1.052]	0.390±0.13 [0.207–0.798]	0.53

p values: unpaired student *t* test