Objective: To characterize anatomical abnormalities of the distal nasolacrimal duct (NLD) in children with congenital obstruction using high-resolution computed tomographic imaging.

Methods: The anatomy of the bone and soft tissue of the NLD and the postductal anatomy of the inferior meatus in 6 children with a wide spectrum of NLD obstructions were imaged by computed tomographic scans and then reconstructed in a 3-dimensional viewer. Images were taken from prior axial (5 children) or coronal (1 child) computed tomographic facial scans at 0.625- or 1.25-mm mm resolution, respectively.

Results: The axial computed tomographic images and 3-dimensional reconstructions showed bony obstructions of the distal NLD in 3 children, membranous obstructions of the distal NLD in 1 child, and a postductal obstruction in the inferior meatus in 1 child. One child had a combined soft tissue obstruction of the NLD and post-NLD obstruction.

Conclusions: This study provides anatomic evidence of a bony or membranous obstruction at the distal portion of the NLD or of a postductal obstruction at the inferior meatus in children with congenital NLD obstruction.


Congenital obstruction of the nasolacrimal duct (NLD) is the most common ocular abnormality of infancy. Typically, NLD obstruction spontaneously resolves by 6 to 8 months of age. The failure of the obstruction to resolve spontaneously is due to abnormal persistence of the distal lacrimal duct epithelium or mechanical obstruction at the valve of Hasner. Each of these mechanisms is based on the subjective impression of the ophthalmic surgeon at the time of NLD probing and the high success rate of NLD probing. The main purpose of our study was to investigate anatomical abnormalities in congenital NLD obstruction using high-resolution computed tomographic (CT) imaging.
1 drop of a 5% fluorescein solution is instilled in the conjunctival fornix, and the presence or absence of retained green fluorescence when illuminated with a short-wavelength (blue) light source is assessed after 5 minutes.

Patients underwent CT imaging of the head and orbits with a Toshiba CBTB-016A 2-dimensional scanner. Patients’ heads were stabilized with a foam cushion. Because the CT scan time was less than 3 seconds, all imaging was performed while the patients were awake. Transaxial images of the head and maxillofacial skull were helically acquired using 2:1 pitch. Continuous axial images of 0.625 mm in thickness (5 of 6 patients; 1 patient at 1.25-mm thickness) were obtained with a 256 × 256 matrix covering a 10-cm area, giving a pixel resolution of 391 µm. The CT images of the orbit were exported in DICOM (digital imaging and communication in medicine) file format with default contrast. The image files were then analyzed using National Institutes of Health ImageJ software version 1.43 (http://rsb.info.nih.gov/ij). Dimensions and volumes of the NLD were obtained by methods previously described. Three-dimensional reconstruction was manually performed in ImageJ by tracing the outline of the NLD from serial slices from the lacrimal sac, when visible, or the lacrimal fossa. The NLD was continuously traced to the distal portion as it enters the inferior meatus. Only 1 patient showed no signal within the NLD (corresponding to air). The remaining patients had a gray signal within the NLD, indicating fluid or volume averaging with bone. Furthermore, the skull and face were reconstructed in ImageJ for reference. Three-dimensional mesh data were exported from ImageJ 3-dimensional plug-in and imported into MeshLab software version 1.3.0 (Visual Computing Laboratory, Institute of the National Research Council of Italy; http://meshlab.sourceforge.net). The data were subsequently smoothed using a surface preserving Laplacian operation. The reconstructed images were visualized by a custom software program (written by J.K.) using the DirectX library version 7.0 (Microsoft Corp.). The software with reconstruction data can be freely downloaded (http://faculty.washington.edu/jokelly/nld3d). The software also includes reconstruction of 3 control subjects reported by Moscato et al.

**RESULTS**

**Figure 1** shows axial images and a 3-dimensional reconstruction of the normal NLD anatomy. The imaging data come from an 11-month-old child in the study by Moscato et al. The most relevant finding is the cylindrical shape of the bony NLD from the proximal to the distal portions. The bulbous dilation beyond the distal portion of the bony NLD represents the anterior portion of the inferior meatus. The transverse diameter is approximately 2.6 mm, and the anterior-posterior diameter is approximately 2.7 mm. The lacrimal sac could not be reliably delineated in the absence of bony boundaries.

**PATIENT 1**

A 3-month-old child with Turner syndrome was seen in consultation for a persistent right dacryocystitis and ipsilateral facial cellulitis previously treated with topical anti-infectives, systemic clindamycin phosphate, and percutaneous incision and drainage of retained mucopurulent material. A pertinent physical examination revealed a febrile infant with distention of the lacrimal sac. **Figure 2** shows axial images through the NLD of each eye prior to surgical intervention. The lacrimal sac proximate 2.7 mm. The lacrimal sac could not be re-
revealed no obstruction. Detection of inflamed nasal mucosa and thickened turbinate mucosa prompted treatment with submucosal and topical corticosteroids, which relieved these symptoms.

PATIENT 2

A 4.5-year-old boy with bilateral epiphora and persistent mucopurulent discharge who has been treated with systemic anti-infectives since infancy was referred for surgical treatment. There was no history of prior NLD probing. The dye disappearance test confirmed delayed clearance, and digital pressure on the lacrimal sac elicited exudate bilaterally. Figure 3 shows the cylindrical shape of the right NLD with tapering of the distal portion, which clearly extends into the inferior meatus. In comparison, the proximal NLD and lacrimal sac are abnormally dilated on the left side, and the distal segment tapers to a point within the bone. Of note, there was no visible communication between the distal segment and the inferior meatus on the left side. During surgery, a bony obstruction was encountered on the right side, but the probe was advanced through the NLD into the inferior meatus, and the lacrimal system was then stented with a bicanalicular Crawford tube. In contrast, there was dense bony resistance on the left side that was overcome by applying firm pressure with a rigid size-2 Bowman probe. However, the bony resistance precluded successful advancement of the flexible Crawford probe on the left side. An external dacrocystorhinostomy on the left side was performed 6 months later.

PATIENT 3

A 22-month-old girl with hypotonia and motor delays has been evaluated for persistent dacryocystitis (left side greater than the right side) since infancy. During surgery, both NLDs were irrigated with saline. The right side was patent; the left side was obstructed and narrowed.
The left side was probed and then dilated with a 2-mm LacriCATH balloon catheter. Because there were persistent symptoms 5 years later, the NLDs were probed and stented bilaterally. Persistent symptoms on the left side prompted a CT scan, serial dilation of the NLD, and fracture of the inferior turbinate. Figure 4 shows the bony narrowing of the distal NLD on the left side. The cross-sectional diameter of the distal portion of the right NLD was 3.1 mm, and the left was 1.1 mm. The 3-dimensional reconstruction shows a cylindrical right NLD that is contiguous with the inferior meatus. By comparison, the left NLD tapers to a punctate opening at the level of the inferior meatus. An endoscopic dacrocystorhinostomy was performed.

**PATIENT 4**

A 17-month-old girl with history of persistent NLD obstruction with recurrent left dacryocystitis was treated with intravenous antibiotics. A fluorescein dye disappearance test revealed a mild obstruction on the right and a moderate obstruction on the left. The severity of fluorescein dye retention was based on the relative intensity of fluorescence at 5 minutes after instillation. She underwent a bilateral NLD probing with stent placement and fracture of the left inferior turbinate under general anesthesia. The distal NLD was tight bilaterally. Four months later, she developed recurrent dacryocystitis on the left, prompting retreatment with systemic antibiotics. A facial CT scan with 0.625-mm resolution was recommended. Figure 5 shows the right NLD extending and opening into the inferior meatus. Although the left NLD terminates in the nose, the inferior meatus is relatively narrower on the left than on the right, and its mucosa is in apposition with that of the medial wall of the maxillary sinus. That is, the NLD obstruction was distal.
to the bony portion of the NLD and presumably at the entry of the NLD into the inferior meatus. The volumes of the right and left NLDs were 106 and 110 mm³, respectively, suggesting that the obstruction was partial or intermittent. The 3-dimensional reconstruction depicts the narrowing of the left inferior meatus due to apposition of the nasal mucosa. She was treated with topical nasal corticosteroids and mupirocin calcium. She remains asymptomatic.

PATIENT 5

A 5-day-old healthy infant presented with a temperature of 38°C and right-sided lacrimal sac mucocele with bluish discoloration of the overlying skin. Organisms were not recovered from blood or cerebrospinal fluid cultures. She was treated with intravenous ampicillin sodium–sulbactam sodium (Unasyn; Pfizer). After 48 hours of antibiotic treatment and persistent dilation of the lacrimal sac, an uncomplicated lacrimal duct probing was performed at the bedside. Figure 6 shows a bilobed lacrimal system with cystic dilation of the lacrimal sac and a distal lacrimal sac mucocele. The bony portion of the NLD was expanded by 2-fold relative to the left side. The volume of the right NLD system was 9.8 times larger on the right side than on the left side. The lacrimal duct probing relieved all symptoms.

PATIENT 6

An 18-month-old child with agenesis of the corpus callosum, a right hemispheric arachnoid cyst without evidence of increased intracranial pressure, and mild motor delays was noted to have bilateral epiphora of the lacrimal sac (right side greater than the left side). There was no history of NLD probing. The abnormal presence of retained fluorescein dye at 5 minutes after instillation confirmed the right NLD obstruction. There was no history of superimposed infections. The axial CT images in Figure 7 show the mild dilation of the right bony NLD. There was bulbous dilation of the soft tissues at the distal portion of the NLD as it extends into the inferior meatus. To date, this child has not had symptomatic infections and has not required probing.
The distal portion of the NLD complex was the anatomic site of obstruction in each of the 6 reported patients. We have demonstrated by high-resolution CT imaging that the NLD obstruction results from 1 of 3 mechanisms. One is the increased proportion of the bony wall relative to the central lumen at the distal portion of the NLD. The second is abnormal persistence of a membrane, presumably nasal and lacrimal mucosa in apposition, at the distal portion of the NLD. The third is narrowing of the inferior meatus with apposition of the nasal mucosa. We propose that each type of distal duct obstruction falls on a continuum that represents distinctive stages in the developmental process that leads to a continuous channel between the NLD and the inferior meatus. A limitation to our study is that 4 of the 6 cases presented represent more extreme developmental abnormalities of the distal NLD.

Patients 1, 2, and 4 had narrowing of the distal portion of the NLD related to preponderance of bone. The abnormal presence of bone at the distal NLD suggests that there were abnormal inducing interactions between the NLD epithelium and the surrounding mesenchyme. The mucosal lining of the primordial nasal lacrimal system first appears at about 6 weeks of fetal development as a groove between the mesenchyme of the lateral nasal and the maxillary prominences. A focal region of thickened epithelium separates from the surface ectoderm, forming the anlage of the nasolacrimal system within the underlying mesenchyme. This region of sequestered epithelium then extends proximally to form the canaliculi and distally to form the nasolacrimal ducts. The linear extension and proliferation of the distal epithelium and its mutual interactions with the surrounding mesenchyme determine the patterning of the distal NLD. The presence of membranous bone or of a bony constriction of the distal NLD is consistent with abnormal interactions between the NLD epithelium and the surrounding mesenchyme during development. We propose that the clinical impression of a membrane and variable resistance at the distal portion of the NLD reflects a histologic continuum that extends from mineralized bone to a bilayer of lacrimal and nasal epithelium.

Patients 5 and 6 had an abnormality that was limited to the soft tissues of the distal NLD. The cross-sectional diameters of the proximal and distal portions of the bony NLD were mildly to moderately dilated secondary to an obstruction at the distal NLD mucosa. We concluded that there was a membranous, rather than bony, obstruction based on cystic dilation of soft tissues at the distal NLD with extension into the inferior meatus. A histological examination of this region in normal newborns reveals a bilayered membrane composed of nasal mucosa in apposition with the NLD epithelium. A bilayered arrangement renders this membrane more resistant to cavitation of the central core of the epithelium than more proximal portions of the NLD. The higher resistance is partly offset by hydrostatic pressure, which is maximal at the lowest point in the NLD and increases with postnatal elongation of the NLD with increasing age. Progressive accumulation of retained tears and the added force of the eyelid blink can lead to spontaneous rupture when the hydrostatic pressure exceeds the tensile strength of a bilayered membrane, which normally is in various stages of involution. The most parsimonious explanation of a membranous obstruction of the NLD is that developmental abnormalities in the central cavitation process of the epithelial bilayer and inadequate hydrostatic pressure lead to the persistence of a membrane at the distal NLD. Further evidence of the role of hydrostatic pressure is demonstrated by dilatation of the bony portion of the NLD in all patients. We suspect that most patients with NLD obstruction encountered in a primary care center have a membranous obstruction similar to the obstructions found in patients 5 and 6, but for whom NLD probing either relieved the symptoms or was not performed.

Patient 2 had a patent NLD with a postductal obstruction due to narrowing of the inferior meatus with apposition of the mucosa lining the inferior meatus and the medial wall of the maxillary sinus. In addition to a distal obstruction, patient 1 had a postductal obstruction due to a thickened nasal mucosa that was successfully treated with local and topical corticosteroids. Increasing the volume of the inferior meatus is a treatment option when it is abnormally small. Medial fracture of the inferior turbinate for the treatment of congenital NLD obstruction was first advocated by Jones and Wobig. In addition to a narrow meatus, apposition of the mucosal lining of the inferior meatus can contribute to the obstruction. Based on the CT findings, we therefore elected to reduce the mucosal thickness with topical corticosteroids and antibiotics. Failure to encounter a persistent NLD obstruction in patient 1 following a successful bicanalicular stent also prompted treatment with a submucosal injection and topical instillation of corticosteroids. Both patients 1 and 2 responded to local corticosteroid treatment of the nasal mucosa.

Historically, the resistance encountered at the distal NLD has been attributed to an obstruction at the valve of Hasner. This valve is thought to be a fold of mucous membrane that guards the distal NLD opening in the nose, preventing retrograde flow of air during increases in intranasal pressure. The nasal fold would have to be a 1-way valve that is normally deflected away from the nasal lumen but rotates toward the lumen during forced nasal expiration when the nares are occluded. Given its origin from the mucosa lining of the NLD and bottom-up deflection pattern, the valve of Hasner is unlikely to underlie the distal obstruction encountered during surgery. We were unable to visualize the valve of Hasner in any of the patients; therefore, we cannot address its possible relationship to the membrane encountered in congenital NLD obstruction.

The potential risks of radiation toxicity in pediatric patients is an important issue. Although the incidence is low, Brenner et al determined that the estimated lifetime risk of fatal cancer related to radiation exposure from a head CT scan was 0.07%. Increased sensitivity of rapidly growing tissues to ionizing radiation, the small cross-sectional area of tissues in children relative to adults, and the cumulative lifetime risk all underlie this concern. The CTDI is the main metric and reflects the radiation ex-
posure of a single slice plus the scatter from surrounding slices. In our study, the CTDI in all patients ranged from 26.05 to 10.42. These values are well below the American College of Radiology CT accreditation CTDI reference level at 75 mGy. Currently, the American College of Radiology does not have a recommended CTDI reference for imaging the head in young children. To reduce the lifetime risk of radiation-induced carcinogenesis, a low-dose CT protocol has been implemented in children who undergo frequent imaging for tumors and hydrocephalus.\textsuperscript{16} Our study demonstrates that adequate imaging and 3-dimensional reconstruction are obtained with a low-dose CT protocol.

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