Assessment of Vibratory Characteristics in Children Following Airway Reconstruction Using Flexible and Rigid Endoscopy and Stroboscopy

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IMPORTANCE Up to half of children have substantial dysphonia after airway reconstruction. Visual assessment of vocal function is valuable. Feasibility of flexible and rigid endoscopy has been reported; however, the clinical utility of stroboscopy has not been examined. Rating of vibratory characteristics, such as mucosal wave and amplitude of vibration, is essential for the development of interventions to improve voice outcomes.

OBJECTIVE To examine (1) clinicians’ ratings of anatomical and physiological features in children following airway reconstruction on initial voice evaluation using videolaryngostroboscopy and (2) the relationship of age to the type of endoscopy used.

DESIGN, SETTING, AND PARTICIPANTS Retrospective medical record review of 32 patients aged 3 to 21 years evaluated for post–airway reconstruction dysphonia between July 2011 and July 2012 at a quaternary care children’s hospital.

INTERVENTIONS Clinical voice evaluation protocol including rigid and/or flexible endoscopy with stroboscopy.

MAIN OUTCOMES AND MEASURES Demographic and voice quality characteristics were collected. The ability to complete endoscopy and ratings of anatomical and/or physiological features were assessed by a consensus of 4 clinicians. A t test was used to determine whether age was a significant factor in successful completion of videolaryngostroboscopy.

RESULTS Of 31 children who underwent flexible videolaryngostroboscopy, 22 (71%) examinations were completed with a distal chip endoscope and 9 (29%) with a fiberoptic. Significant differences were found in age between children who completed the distal chip vs fiberoptic examination (mean [SD], 7.3 [2.7] vs 5.5 [6.2] years; P = .05). Rigid endoscopy was attempted for 14 (44%) of 32 patients; 9 examinations (64%) were successful. Significant differences were found in age between patients for whom a rigid endoscopy could be successfully completed vs those for whom it was not (mean [SD], 12.9 [3.4] vs 6.2 [2.1] years; P < .001). Eighteen (56%) were glottic phonators, 8 (25%) supraglottic, and 6 (19%) aphonic. Vibratory characteristics were visible in 10 of 37 examinations (27%); 6 (16%) had ratable characteristics.

CONCLUSIONS AND RELEVANCE Endoscopy can be successfully completed in most children who have undergone airway reconstruction, most often using a distal chip endoscope. We found that vibratory characteristics were often not assessed adequately using videolaryngostroboscopy. Further work identifying imaging modalities that better display vibratory characteristics, such as high-speed videoendoscopy, may provide new insight into vocal function and lead to a more thorough evaluation.
Dysphonia is common in children following airway reconstruction, with up to half having a substantial dysphonia.1,2 Because alterations of laryngeal anatomic and physiologic features have been reported in patients with a history of prolonged intubation and/or airway reconstruction surgery, the visual assessment of phonation in this clinical population has important implications for evaluating vocal function and guiding voice treatment.2-6

Videolaryngostroboscopy (VLS) has become the most commonly used visualization tool to assess anatomy and physiology of vocal function and often plays a substantial role in diagnosis and treatment planning for children with voice disorders. Endoscopic characteristics of laryngeal closure and supraglottic patterns in children following airway reconstruction have been described; however, the ability to rate stroboscopic characteristics (eg, mucosal wave, amplitude of vibration) to measure vibratory tissue characteristics during phonation has not been reported.2-7 Thus, the purpose of this study was 2-fold: (1) to examine clinicians’ ratings of anatomic and physiological features in children following airway reconstruction using VLS video images and (2) to examine the relationship of age to the type of endoscopy performed.

Methods

We searched our voice clinic database to identify all patients who were seen for a voice evaluation following airway reconstruction at Cincinnati Children’s Hospital Medical Center (CCHMC) in the Center for Pediatric Voice Disorders, Cincinnati, Ohio, between July 2011 and July 2012. Inclusion criteria for the study were (1) initial voice evaluation at CCHMC, (2) completion of at least 1 airway reconstruction procedure, and (3) age 3 to 21 years.

A voice evaluation included assessment of acoustic, aerodynamic, and perceptual properties, and VLS. Videolaryngostroboscopy samples from patients meeting our inclusion criteria were later rated for this study by a consensus of 3 speech-language pathologists and 1 pediatric otolaryngologist during a single rating session. The VLS examinations were retrieved for the consensus ratings on 1 of 2 video server storage systems, (1) the KayPENTAX endoserver and (2) image stream server. Key endoscopic variables rated for this study included (1) type of endoscope used (2.2/2.4-mm fiberoptic, 3.2-mm distal chip, 10-mm/6-mm rigid), (2) source of phonation (eg, vocal folds, false vocal folds), (3) presence of visible vibratory patterns (yes/no), and (4) ability to rate discrete vibratory patterns (eg, mucosal wave, amplitude of vibration) (yes/no).

Feasibility was evaluated independently for 2 factors: age of patients undergoing successful flexible or rigid endoscopy and stroboscopy, and ability to view and rate discrete vibratory characteristics. Feasibility for age was defined in our study as the age at which a child was able to tolerate the use of a specific type of endoscope (flexible and rigid). Feasibility for stroboscopy features was defined as the capability to visualize and rate discrete vibratory features of phonation (by consensus ratings of speech-language pathologist and pediatric otolaryngologist). This study was approved by the CCHMC Institutional Review Board. Informed consent was obtained on initial voice clinic visit.

Initial Voice Evaluation

All patients underwent the following voice assessment protocol as has been previously described: perceptual evaluation (consensus auditory-perceptual evaluation of voice [CAPE-V]), acoustic and aerodynamic measurements (eg, maximum phonation time, fundamental frequency, intensity, mean airflow, subglottic pressure), voice handicapping index (pediatric voice handicap index [PVHI]), and VLS.2 We used a standardized protocol for rigid and flexible endoscopy for VLS.

Most children underwent rigid (depending on age and maturity) and flexible endoscopy with stroboscopy on their initial visit. Children and parents were prepared for the rigid and flexible examinations by a child-friendly explanation prior to examination. First, use of a rigid endoscope, either a 70° 10-mm adult (KayPENTAX model 9106) or 6-mm pediatric (KayPENTAX model 9108) rigid endoscope, was attempted by the pediatric speech-language pathologist. Selection of suitable candidates for rigid endoscopy was based on maturity and age. No topical oral or sedative medication was given prior to rigid examinations. If a child who initially was predicted to be able to tolerate a rigid endoscopy was unable to do so, then only flexible endoscopy was performed.

Next, flexible endoscopy was performed by the pediatric otolaryngologist. Prior to the insertion of a flexible endoscope, the topical anesthetic pseudophedrine hydrochloride-pontocaine hydrochloride and viscous lidocaine hydrochloride was applied to the nose. Use of a flexible 3.2-mm distal chip endoscope (KayPENTAX or Olympus) was initially attempted; however, if it was determined by the pediatric otolaryngologist that the nasal cavity of the child was too small for the distal chip, a smaller flexible fiberoptic endoscope (2.4-mm fiberoptic, KayPENTAX; or 2.2-mm fiberoptic, Olympus) was used. All examinations were recorded and reviewed with the patient and family.

Statistical Analysis

All data were collected in a database and further analyzed with commercially available software (SAS, version 9.1; SAS Institute). Categorical variables are reported by frequency. Continuous variables are reported as means with standard deviations. A t test was used to compare groups based on age.

Results

Thirty-two patients (23 males; 9 females), with a mean (SD) age of 9.3 (4.4) years (range, 3-19 years), were identified who met the inclusion criteria. The demographic and clinical characteristics of our population are presented in Table 1. As noted in Table 1, a single-stage laryngotracheoplasty was the most common airway reconstruction surgery (18 [56%]) in our population. Clinician’s perceptual ratings of overall voice quality, using the CAPE-V, were least severe in glottic (vocal fold) phonators, more severe in supraglottic (tissue above the vocal folds)
phonators, and most severe in aphonic speakers. This same trend was seen in the scores of the parent-reported perceptual tool, the PVHI. A total of 45 endoscopy with stroboscopy examinations were attempted in the 32 study patients (Table 2), with 40 examinations successfully completed (at least an anatomical view was obtained).

For endoscope type and source of phonation, results are reported on the basis of the number of study patients (N = 32). Results for tissue vibration using stroboscopy (visibility and ability to provide discrete ratings of vibratory tissue) results are reported on the basis of the total number of examinations (N = 37; 5 rigid examinations were not included because of unsuccessful attempts and 3 were not included because of aphony).

**Endoscope Type**

Fourteen (44%) of the children underwent rigid endoscopy on their initial visit, with 9 (64%) examinations successfully completed (at least an anatomical view was obtained) (Table 2). There was a statistically significant difference based on age as a factor in those for whom a rigid endoscopy could be successfully completed vs those for whom it was not (P < .001; mean [SD] age, 12.9 [3.4] vs 6.2 [2.1] years).

All children tolerated flexible endoscopy examination (1 child underwent only rigid endoscopy due to high success of examination). Twenty-two of 31 (71%) were able to complete the evaluation using a distal chip flexible endoscope (3.2-mm KayPENTAX) and 9 of 31 (29%) with fiberoptic flexible endoscope (2.2-mm Olympus or 2.4-mm KayPENTAX). Statistically significant differences were found based on age as a factor in those who were able to complete the distal chip vs fiberoptic flexible endoscopy (P = .05; mean [SD] age, 7.3 [2.7] vs 5.5 [6.2] years).

**Source of Phonation**

Anatomic structures of phonation (source of phonation) were identified in 31 of 32 (97%) patients. Eighteen (56%) of the children appeared to use vocal folds for phonation, 8 (25%) supraglottic tissue, and 6 (19%) had no visible contact of laryngeal tissue (aphonic). The supraglottic phonators used a variety of phonatory patterns: ventricular folds, arytenoid against the petiole of the epiglottis, arytenoid against the ventricular fold, and 1 used a variety of supraglottic tissues that could not be precisely categorized or identified.

**Vibratory Characteristics**

Stroboscopy was used in all examinations to assess tissue vibratory characteristics. Vibratory characteristics were visible in 10 of 37 (27%) examinations. Visible tissue vibratory characteristics by scope type are shown in Figure 1. Discrete ratings (eg, ratings of mucosal wave, amplitude of vibration) were accomplished in 6 (16%) of the examinations. During examinations in which discrete ratings of tissue vibration were accomplished, the rigid endoscope provided the highest percentage of visible and ratable vibratory characteristics, followed by the distal chip flexible endoscope and the fiberoptic flexible endoscope.
by the distal chip flexible endoscope. Discrete ratings of visible tissue vibratory characteristics by scope type are shown in Figure 2.

Discussion

Approximately half of children who undergo airway reconstruction are known to have dysphonia, with a substantial portion presenting with severe dysphonia. Dysphonia is associated with social withdrawal and depression, which can have a negative influence on social, emotional, educational, and occupational outcomes. The ability to assess tissue vibratory characteristics using stroboscopy in the post-airway reconstruction population has important clinical implications for planning and execution of surgical and behavioral treatments. Previous studies have described vocal quality and endoscopic characteristics in children who have undergone airway reconstruction but not the ability to measure stroboscopic characteristics of tissue vibration. Results from our study demonstrated that all children who had undergone airway reconstruction tolerated a flexible and/or rigid endoscopy with good visualization of anatomic structures but poor visibility of tissue vibratory characteristics. This is an important finding because visual documentation of vocal function is routinely used for treatment planning in this population.

The age at which flexible endoscopy could be completed successfully in our study is similar to those studies that assessed children with common voice disorders such as nodules and cysts. When comparing the distal chip with fiberoptic flexible endoscopy, statistically significant differences in age were found in patients for whom an examination could be completed successfully using the distal chip vs fiberoptic flexible endoscope (P = .05; mean age 7.3 vs 5.5 years). We were not surprised by this finding because the larger size of the distal chip endoscope (3.2 mm) vs the flexible endoscope (2.4 mm) makes it more likely to be accommodated by the relative larger nasal anatomical structures of the older (7.5 years) children. We would recommend on the basis of our findings that children at age 7.5 years can consistently undergo distal chip flexible VLS with the 3.2-mm scope. A newer distal chip flexible endoscope (2.8 mm) is now available and may allow children to successfully undergo this examination at an early age. The distal chip endoscope may be the optimal choice for visualizing and documenting anatomical structures in children following airway reconstruction as 71% of the children, with a mean age of 7.3 years, were able to tolerate this examination.

Furthermore, a higher percentage of the distal chip examinations provided visible vibratory characteristics (6 distal chip vs 1 fiberoptic) (Figure 1) and ability to rate discrete vibratory tissue characteristics (4 distal chip vs 0 fiberoptic) (Figure 2) when compared with fiberoptic endoscopes. These examinations frequently provide superior images in terms of both quality and size, leading to a more successful voice evaluation with the aid of anatomy and physiology assessment. Future development of smaller distal chip endoscopes may improve diagnostic capabilities in younger children.

Similarly, our results for successful rigid endoscopy (defined as obtaining an anatomical view) were comparable between this study and previous studies in children with common voice disorders. Previous studies reported that children aged 12 years and older were able to tolerate rigid endoscopy (with and without the use of topical and sedative medication). In our study, children who were able to tolerate rigid endoscopy after airway reconstruction had a mean age of 12.9 vs 6.2 for those who could not (P < .001), and no topical or sedative medication was used. As the use of smaller diameter rigid endoscopes becomes common practice in pediatric voice clinics, the success rate may increase and younger patients may be successfully evaluated. We expect that as these tools become more available we should see an improvement in our ability to assess anatomic and physiologic aspects of pediatric voice.

Anatomy ratings of phonation source demonstrated that 56% of our subjects were glottic phonators (vocal folds), 25% supraglottic phonators (tissue above the vocal folds), and 19% aphonics (no visible vibrating tissue). Patients in our study with supraglottic phonation demonstrated phonation patterns on VLS similar to those of earlier reports: lateral (ventricular folds), anterior-posterior, arytenoid-petiole, and mixed (use of supraglottic and vocal folds). Often trial therapy occurs during our acoustic portion of the voice evaluation; all but 1 of the aphonics speakers in this study were able to obtain audible phonation during an acoustic task (most likely using supraglottic tissue). When phonation occurred during trial therapy, it was for short periods. Once the patient was performing VLS, adequate phonation times were not obtained. Several reasons may account for this; anxiety, coupled with a slightly different head position, may keep the patient from recreating the new voice that was heard during the acoustic portion. Once voice therapy is initiated and the patient learns the new phonation pattern and is able to sustain phonation for longer periods of time, visualization of phonatory patterns with VLS may be more successful.

The evaluation of tissue vibration during phonation is necessary to assess and document treatment planning and outcomes. In this study, the low percentage of evaluable vibratory characteristics in children who had undergone airway reconstruction highlights the need to improve current

Figure 2. Discrete Ratings of Vibratory Tissue Characteristics by Scope Type

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No. of Examinations

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clinical visual diagnostic assessment tools. In our study, vibratory characteristics were visualized and rated in only 6 of the 37 examinations (Figure 2). It is known that the visualization of “slow motion” vocal fold vibration on VLS is only possible when the acoustic signal used for “tracking” is periodic.15,26 The majority of post–airway reconstruction patients present with type II or III acoustic signals (aperiodic), which cannot be consistently synchronized with the strobe light.17 The inability to synchronize vocal fold vibration affects the interpretation of the examination because the simulated slow-motion visualization provided by stroboscopy becomes chaotic. That is, random images of multiple phonatory cycles are presented, frequently erroneously interpreted as “irregular vibrations.” Therefore, in many of these patients stroboscopy does not allow for visualization or discrete rating of the vibratory tissue characteristics.4 Additional issues pertaining to the inability to visualize vibratory characteristics in this study were due to anatomical specifics such as arytenoid prolapse (obscuring view of vibrating tissue) (n = 2), dark images (on fiberoptic) (n = 2), and crying (n = 1), or any combination of these (n = 2).

Advancements in imaging technology such as high-speed videoendoscopy (HSV) can overcome these limitations by avoiding reliance on the acoustic signal and therefore allow the visualization of vocal fold vibratory features regardless of acoustic signal type or vocal fold behavior (eg, crying).15 We expect HSV to allow more successful evaluation of the vibratory features of children following airway reconstruction. Further studies using HSV in this patient population are warranted.

There are several limitations to our study. Many of the patients may have had previous experience with this type of examination prior to visiting our clinic, which may have increased our success rate of performing endoscopy with certain endoscopes. Conversely, if the patient had a bad previous experience, then cooperation and/or tolerance would have been decreased compared with a patient’s first examination with this modality. Second, our clinic acquired the pediatric rigid scope (6 mm) during the study period. This may have affected the age at which patients who have undergone airway reconstruction tolerate rigid endoscopy. We suspect that as we increase the use of pediatric rigid endoscopy, we will see an increase in successful rigid examinations, especially in younger populations. Last, our institution is a quaternary referral center for complex airway reconstruction and voice problems and consequently has a higher volume of patients who have undergone airway reconstruction compared with other institutions and therefore may reflect children with more complicated post–airway reconstruction voice problems. Despite these limitations, we believe that the study accurately demonstrates the feasibility with regard to the age at which flexible and rigid endoscopes can be used successfully in this population and is strengthened by our experience managing and evaluating these patients in a high-volume setting.

Conclusions
Our study demonstrated that clinicians were able to successfully perform flexible and/or rigid endoscopy examinations in children who have undergone airway reconstruction. We noted that age was associated with the type of endoscope that could be used successfully (9 rigid, 22 distal chip, 9 fiberoptic) during the examination. Although almost all patients were able to undergo endoscopy examination, only gross anatomical structures used during phonation were consistently visualized, whereas vibratory tissue characteristics could not be assessed by stroboscopy in most patients. The ability to use stroboscopy to measure vibratory characteristics (eg, mucosal wave, amplitude of vibration) in these patients has a significant effect on the ability to elucidate physiological constructs during vibration and to guide surgical, medical, and behavioral interventions. Advancements in imaging techniques, such as smaller distal chip endoscopes and HSV, may be useful in improving the ability to rate vibratory characteristics in this population, thus refining surgical and behavioral intervention outcomes.

REFERENCES


