Assessment of Vocal Fold Mobility Before and After Cardiothoracic Surgery in Children

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Objectives: To assess the incidence of vocal fold immobility (VFI) after cardiothoracic surgery in children and to determine the factors potentially associated with this outcome.

Methods: Flexible laryngoscopy to assess vocal fold mobility was performed before surgery and within 72 hours after extubation in 100 pediatric patients who underwent cardiothoracic procedures. The 2 operating surgeons recorded the surgical technique and their impression of possible injury to the recurrent laryngeal nerve. The presence of laryngeal symptoms, such as stridor, hoarseness, and strength of cry, after extubation was documented.

Results: Of 100 children included in this study, 8 had VFI after surgery. Univariate analyses showed that these 8 patients were younger and weighed less than the patients with normal vocal fold movement. Monopolar cautery was used in all patients with VFI. On univariate analysis, factors statistically significantly associated with VFI were circulatory arrest and dissection or ligation of the patent ductus arteriosus, left pulmonary artery, right pulmonary artery, or descending aorta. However, multivariate analyses failed to show these associations.

Conclusions: The incidence of VFI after cardiothoracic surgery in our population of children was 8.0% (8 of 100). Of several factors found to be potentially associated with VFI on univariate analysis, none were significant on multivariate analysis. This may be a result of the few patients with VFI. A larger multicenter prospective study would be needed to definitively identify factors associated with the outcome of VFI.

studies was likely underestimated. More recently, 4 prospective studies21-24 observed VFI prevalences of 9.1% to 52.2% among children who underwent cardiothoracic procedures. The higher prevalence observed in prospective studies is partially explained by the fact that every child had his or her larynx examined following the cardiothoracic procedure, regardless of the presence of laryngeal symptoms.

No study to date has performed vocal fold assessment before and after a cardiothoracic procedure in children. In a child with a postoperative diagnosis of VFI in whom vocal fold motion was not assessed before surgery, one cannot rule out other possible causes, such as birth trauma,25 familial syndromes,26 or previous cardiothoracic procedures, as well as cardiovascular syndrome (in which a hypertensive pulmonary artery compresses the left RLN between the aorta and the trachea).27

The primary objective of this study was to assess the incidence of VFI after cardiothoracic surgery. A secondary aim was our attempt to determine the factors potentially associated with this outcome.

STUDY DESIGN

All pediatric patients who underwent cardiothoracic surgery at BC Children’s Hospital, Vancouver, British Columbia, Canada, between November 19, 2008, and August 19, 2009, were included in the study. Patients were excluded if preoperative flexible laryngoscopy was not performed because of endotracheal intubation before surgery. Informed consent for flexible laryngoscopy was provided. This study initially received institutional approval as a quality assurance review, and full ethics approval subsequently was obtained from the institutional review board.

Flexible laryngoscopy was performed immediately before surgery in the operating room and within 72 hours after extubation using a laryngoscope with an external diameter of 2.4 mm (ENT-1000; Vision-Sciences, Inc, Orangeburg, New York). The laryngoscope was attached to a microcamera and a recording system that permitted storage of the video stream images. All videos were reviewed by one of us (F.K.K.) to confirm the presence or absence of vocal fold movement.

The following information was obtained from each patient’s medical record: (1) baseline demographics, including date of birth, age at surgery, weight at surgery, and cardiothoracic diagnosis, and (2) factors potentially associated with the outcome of VFI, including use of cautery, topical cooling, circulatory arrest, duration of intubation, use of cardiopulmonary bypass, surgical site (sternotomy vs thoracotomy), intraoperative transesophageal echocardiography (TEE) monitoring, and dissected structures (patent ductus arteriosus [PDA], aortic arch, descending aorta, ascending aorta, main pulmonary artery, left pulmonary artery, and right pulmonary artery).

Following surgery, the 2 operating surgeons (J.G.L. and A.I.C.) recorded whether the RLN was visualized during surgery and what their impression was of possible injury to the RLN. The presence of laryngeal symptoms, including stridor, hoarseness, and strength of cry, was documented following extubation. The investigator (L.F.C.) was not blinded to symptoms at the time when vocal fold movement was assessed.

STATISTICAL ANALYSIS

Descriptive statistics were used to characterize the 2 study groups. Age and weight were given as medians (interquartile ranges) and categorical variables as absolute frequencies (percentages). The Mann-Whitney nonparametric test was used for variables with asymmetrical distribution. Relative risks (95% confidence intervals) were calculated to indicate the univariate strength of association. Logistic regression analyses were performed with factors that were significantly associated with VFI on univariate analysis and with others that were deemed clinically important.

RESULTS

Between August 19, 2008, and November 19, 2009, 161 children underwent cardiothoracic surgery at BC Children’s Hospital. Among 161 children, 24 (14.9%) could not have their larynx examined before surgery because of endotracheal intubation, and 4 (2.5%) had VFI before surgery and were excluded from the study. Of the remaining 133 children, 25 (18.8%) had no consent by a legal guardian, and 8 (6.0%) were not examined before surgery because the investigating team (L.F.C., F.K.K., and M.F.) was not notified of a cardiothoracic procedure. The remaining 100 children were included in the study.

Of these 100 children, 41 were female, and 59 were male. At the time of surgery, their median age was 7.5 months (interquartile range, 3.8-34.7 months), and their median weight was 7.3 kg (interquartile range, 4.8-14.9 kg). Thirty-two children had undergone a previous cardiothoracic procedure.

UNIVARIATE ANALYSIS

The prevalence of VFI following cardiothoracic surgery was 8.0% (95% CI, 2.5%-13.4%). All 8 VFI cases were unilateral and left sided. Children without VFI were older and heavier at the time of surgery (Table 1). One surgeon (J.G.L.) performed 59% of the surgical procedures, and the other surgeon (A.I.C.) performed 41.0%.

No difference in VFI frequency was observed between patients operated on by the 2 surgeons. Monopolar cautery was used for dissection and hemostasis in all patients with VFI (Table 2). On univariate analysis, factors statistically significantly associated with VFI were circulatory arrest and dissection or ligation of the PDA, left pulmonary artery, right pulmonary artery, or descending aorta. The probability of VFI after surgery was increased among children whose surgeon had the impression that there was injury to the RLN during sur-
surgery and among children who demonstrated stridor, weak cry, and hoarseness. Notably, there was a higher chance of VFI whenever the RLN was visualized by the cardiac surgeon.

One of 8 children with VFI died of cardiac surgery complications during subsequent admission. Recovery of vocal fold movement was observed in 3 of the remaining 7 children on assessment at 3 months’ follow-up. No differences in possible associated factors were observed between the 3 children who recovered and the 4 children who did not recover.

MULTIVARIATE ANALYSES

To explore whether the variables identified in the univariate analysis would still provide evidence of association when combined with other factors, several exploratory logistic regression analyses were undertaken. The initial analysis included the variables thought to be the most relevant, including visualization of the RLN, surgical impression of injury to the RLN, dissection of the PDA or left pulmonary artery, and stridor following extubation. While all 5 variables showed a potential association in the univariate analyses, this disappeared when all 5 variables were included in the same model. The most likely explanation is the few patients with VFI. Removing the 2 least significant variables from this group did not improve the model. The next logistic regression model looked at the effect of patient age and dissection of the PDA on VFI. Age was not important, but dissection of the PDA showed promise of association, although it was not statistically significant. Classification into patients with mobile vs immobile vocal folds did not change the results from the null model (ie, no variables were added). Finally, a composite variable was constructed comprising dissection of the left and right pulmonary arteries and descending arch. If any one underwent dissection, the new variable recorded a dissection. The final model entered dissection of the PDA as the composite variable and cautery with VFI as the dependent variable. Again, there was no improvement in the ability to predict VFI, although dissection of the PDA was the strongest contributor to the model.

COMMENT

The incidence of VFI among 100 pediatric patients who underwent cardiothoracic surgery at our institution was 8.0%. Retrospective studies found a prevalence of VFI varying from 2.8% to 8.8% (Table 3). These retrospective studies have in common the fact that only symptomatic children who underwent surgery were included. It is possible that the incidence of VFI is higher in asymptomatic children, but this needs further investigation.

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### Table 2. Clinical and Surgical Characteristics of the Cohort

<table>
<thead>
<tr>
<th>Variable</th>
<th>Children With VFI (n = 8)</th>
<th>Children Without VFI (n = 92)</th>
<th>Relative Risk (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeons’ impression of possible injury to the RLN</td>
<td>3 (37.5)</td>
<td>2 (2.2)</td>
<td>17.2 (3.4-88.6)</td>
</tr>
<tr>
<td>Visualization of the RLN during surgery</td>
<td>6 (75.0)</td>
<td>15 (16.3)</td>
<td>4.6 (2.5-8.5)</td>
</tr>
<tr>
<td>Dissection or ligation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDA</td>
<td>7 (87.5)</td>
<td>35 (38.0)</td>
<td>2.3 (1.6-3.2)</td>
</tr>
<tr>
<td>Left pulmonary artery</td>
<td>5 (62.5)</td>
<td>19 (20.7)</td>
<td>3.0 (1.6-5.9)</td>
</tr>
<tr>
<td>Right pulmonary artery</td>
<td>5 (62.5)</td>
<td>23 (25.0)</td>
<td>2.5 (1.3-4.8)</td>
</tr>
<tr>
<td>Aortic arch</td>
<td>3 (37.5)</td>
<td>16 (17.4)</td>
<td>2.3 (0.8-5.9)</td>
</tr>
<tr>
<td>Ascending aorta</td>
<td>5 (62.5)</td>
<td>78 (84.8)</td>
<td>0.7 (0.4-1.3)</td>
</tr>
<tr>
<td>Main pulmonary artery</td>
<td>4 (50.0)</td>
<td>41 (44.6)</td>
<td>1.1 (0.5-2.3)</td>
</tr>
<tr>
<td>Descending aorta</td>
<td>4 (50.0)</td>
<td>11 (12.0)</td>
<td>4.2 (1.7-10.2)</td>
</tr>
<tr>
<td>Transesophageal echocardiography</td>
<td>2 (25.0)</td>
<td>56 (60.9)</td>
<td>0.4 (0.1-1.4)</td>
</tr>
<tr>
<td>Circulatory arrest</td>
<td>3 (37.5)</td>
<td>5 (5.4)</td>
<td>6.9 (2.0-23.0)</td>
</tr>
<tr>
<td>Topical cooling</td>
<td>3 (37.5)</td>
<td>21 (34.8)</td>
<td>1.1 (0.4-2.8)</td>
</tr>
<tr>
<td>Cautery</td>
<td>8 (100)</td>
<td>60 (65.2)</td>
<td>1.5 (1.3-1.8)</td>
</tr>
<tr>
<td>Laryngeal symptoms after surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stridor</td>
<td>3 (42.8)</td>
<td>3 (8.5)</td>
<td>4.5 (1.3-15.3)</td>
</tr>
<tr>
<td>Weak cry</td>
<td>8 (100)</td>
<td>7 (7.6)</td>
<td>13.1 (6.5-26.8)</td>
</tr>
<tr>
<td>Hoarseness</td>
<td>5 (62.5)</td>
<td>12 (13.0)</td>
<td>4.8 (2.3-10.2)</td>
</tr>
</tbody>
</table>

Abbreviations: PDA, patent ductus arteriosus; RLN, recurrent laryngeal nerve; VFI, vocal fold immobility.
motic children had their larynx examined following surgery, which likely underestimates the prevalence of VFI following a cardiothoracic procedure. Previous prospective studies\textsuperscript{17-20} in which every child, despite the presence or absence of symptoms, had his or her larynx examined following a cardiothoracic procedure found a prevalence of VFI varying from 9.1\% to 52.2\% (Table 3). There are 3 possible explanations for the lower frequency of VFI in our study compared with that in previous prospective studies. First, we included children who underwent all types of cardiothoracic surgical procedures and not just ligation of the PDA. In our cohort, 7 of 8 patients with VFI underwent ligation of the PDA, and the remaining child underwent ligation of a previous left Blalock-Taussig operation that required similar dissection. Second, we excluded children who had VFI before the cardiothoracic procedure. Flexible laryngoscopy performed before surgery in our population revealed 4 cases of VFI. These 4 children had a history of cardiothoracic surgery. Third, because children with endotracheal intubation before the cardiothoracic procedure could not undergo examination of the larynx beforehand, most premature newborns who were surgical candidates were excluded from our cohort. We observed that this excluded group was younger and smaller at the time of surgery and had more surgical interventions involving dissection of the PDA.

Younger age and lower weight at surgery were significantly associated with VFI on univariate analysis. Compared with children who do not have VFI, children who have VFI are smaller at birth,\textsuperscript{18,19} are more premature,\textsuperscript{1,18,19} and are younger and weigh less at the time of dissection of the PDA.\textsuperscript{16,18}

In our study, the duration of endotracheal intubation was not statistically different between children with vs without VFI, and there were no reports of traumatic endotracheal intubation. We did not perform electromyography or palpation of the cricoarytenoid joint to rule out laryngeal fixation because each of these is an invasive procedure that requires general anesthesia. Our findings suggest that VFI was probably a result of injury to the RLN during surgery and did not occur from the endotracheal tube.

Use of monopolar cautery for dissection and hemostasis for the surgical procedure was performed in all patients with VFI; however, it was significantly associated with VFI only on univariate analysis. No previous study has shown this association. Demyelination within the RLN following thermal injury was the proposed mechanism of nerve dysfunction.

Circulatory arrest was also significantly associated with VFI on univariate analysis. It was performed if necessary to open a blood-filled structure that could not be isolated from the rest of the circulation, mostly aortic arch repairs with dissection down to the level of the PDA and close to the RLN. This is also the case in left pulmonary arterioplasty surgery, where dissection is frequently carried through the pericardium and on the left lower pulmonary lobe close to the RLN. In contrast, bypass was not associated with VFI. Transesophageal echocardiography almost reached statistical significance on univariate analysis; notably, children who had intraoperative TEE monitoring had a lower chance of developing VFI. Kawahito et al\textsuperscript{21} also found no association between TEE and VFI among 116 patients older than 5 years who underwent cardiothoracic surgery. In our study, logistic regression models failed to corroborate results of the univariate analysis, possibly because of the few patients with VFI.

Stridor, hoarseness, and weak cry were associated with VFI on univariate analysis but, like TEE, showed no association on multivariate analysis. One possible bias is the fact that assessment of a child’s symptoms was frequently performed at the same time as flexible laryngoscopic examination with visualization of the vocal fold status. This bias could have been avoided if voices of all children had been recorded and further analyzed by another pediatric otolaryngologist blinded to the laryngeal images. This study is under way.

Impression of injury to the RLN by the surgeon was associated with VFI on univariate analysis. A notable finding is that there was higher risk of VFI whenever the surgeon visualized the RLN. Normally, pediatric cardiothoracic surgeons do not search for the RLN; when this nerve is visualized, it is because it is because the surgical procedure was in close proximity to the RLN. In thyroid surgery, it is a standard of care to identify the RLN to avoid potential VFI.\textsuperscript{24} In this situation, there is usually enough room when the nerve is visualized to avoid significant cautery or traction injury. However, in pediatric cardiothoracic surgery, the surgeon has already dissected or cauterized too close to the RLN when the nerve is seen. A possible way to identify the RLN during surgery without dissecting too closely is via electromyography. Odgaard et al\textsuperscript{22} developed a technique to monitor the RLN during video-assisted thoracoscopic surgery for ligation of the PDA. A probe allowed direct stimulation of the left RLN inside the thorax, and needle electrodes placed percutaneously in the neck allowed recording of evoked electromyograms from both RLNs using a neurological monitor. Electromyography of the left RLN was easily obtained in 59 of 60 children studied, and the authors concluded that this technique was easy to perform and effective in identifying the position of the RLN.

In conclusion, the patients in our study with VFI were younger and weighed less than the patients with normal vocal fold movement. Univariate analysis yielded significant findings for several variables; however, these results were not significant on multivariate analysis. Although circulatory arrest and dissection or ligation of the right and left pulmonary arteries and the descending aorta...
were associated with VFI, they may represent confounding
factors. Further study with multivariate analyses among
more patients is needed to definitively identify factors asso-
ciated with the outcome of VFI. Monopolar cautery was
used in all patients with VFI, and we had theorized that
this might have a role in thermal injury to the RLN. How-
ever, monopolar cautery was found to have a weak asso-
ciation, which may be because of the few patients with VFI
in this study. Additional investigations are required to
determine the causality of monopolar cautery injury to
the RLN, and comparisons with bipolar cautery would be
useful. Postoperative flexible laryngoscopy is indicated if
injury to the RLN is perceived or if laryngeal symptoms are
present. Preoperative flexible laryngoscopy in this patient
population should be considered.

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and Fiori. Drafting of the manuscript: Carpes, Kozak,
Leblanc, and Campbell. Critical revision of the manu-
script for important intellectual content: Carpes, Kozak,
Leblanc, Human, Fandino, Ludemann, Moxham, and
Fiori. Statistical analysis: Carpes. Administrative, tech-
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