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Effects of Subglottic Stenosis and Cricotracheal Resection
on Voice Production in Women

Lisa Marie Mattei

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

Effects of Subglottic Stenosis and Cricotracheal Resection on Voice Production in Women

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Master of Science

Subglottic stenosis (SGS) is a narrowing of the airway in the region of the cricoid cartilage below the vocal folds and above the tracheal rings. Individuals with SGS experience difficulty breathing at rest and during exertion both of which become increasingly difficult with the level of stenosis severity. Some individuals also experience negative voice changes. Individuals whose stenoses significantly impact breathing generally require medical procedures or surgery, either balloon dilation or cricotracheal resection (CTR). CTR has been shown to improve patients' ability to breathe, but it can also result in permanent vocal changes. Alternatively, balloon dilation results in similar breathing improvements but for a relatively short period of time. Many studies have been published on the effectiveness of CTR; however, only a few have examined the effects of CTR on vocal production. The purpose of this study is to quantify the acoustic and auditory-perceptual features of subglottic stenosis and examine possible acoustic and auditory-perceptual changes in voice production following a revised CTR aimed to minimize voice impact in a group of women. A retrospective chart review identified women with idiopathic SGS who received revised CTR at The University of Utah Voice Disorders Center between 2008 and 2014. Presurgical and postsurgical groups included patients with both pre and post recordings ($n = 11$) as well as patients with only pre ($n = 6$) or post ($n = 9$) recordings. Acoustic quantification of voice signal periodicity, as well as cepstral, spectral, and fundamental frequency (F_0) analyses were performed. Auditory-perceptual ratings of overall quality and monotonicity were performed. Cross-sectional and pre-post surgery analyses were completed. Aggregate analyses revealed that both pre and posttreatment SGS patients demonstrated voice disorders in the mild to moderate severity range. Pre-post comparisons indicated no significant voice change after surgery. Mean fundamental frequency decreased from 215 Hz ($SD = 40$ Hz) to 201 Hz ($SD = 65$ Hz). Voice disorder severity based on the cepstral spectral index of dysphoniaTM for sustained vowels decreased (i.e., improved) from 41 ($SD = 41$) to 25 ($SD = 21$) points. Semitone standard deviation (2.2 semitones) was equivalent from pretreatment to posttreatment. Auditory-perceptual ratings demonstrated similar results. These preliminary results indicate that the revised CTR procedure is promising in minimizing adverse voice effects. Future research is needed to determine causative factors for pretreatment voice disorders, as well as to optimize treatments in this population.

Keywords: subglottic stenosis (SGS), cricotracheal resection (CTR), voice disorders, semitone standard deviation (STSD)

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“For with God all things are possible” (Mark 10:27). This is as true in research as it is in any other aspect of life. This thesis is the result of countless hours devoted by many inspired and devoted people across multiple professions. Foremost of whom is my thesis chair Dr. Kristine Tanner, who bridged the resources and talents of people from multiple universities to bring about an incredible research opportunity. I’m so grateful to have had her as my personal and professional mentor. Her confidence in me and her enthusiasm for the field of Speech-Language Pathology were motivating and inspiring through the many deadlines and challenges of research. I would also like to thank my thesis committee for sharing their talents and encouragement with me every step of the way. Special thanks also goes to those who funded this study, especially the National Institute on Deafness and Other Communication Disorders at the National Institutes of Health (R01DC009606-05) and the David O. McKay School of Education research grant, Brigham Young University. Last, but not least, I deeply appreciate the love and sacrifices of my family who provided the means necessary for me to succeed. They truly sustained me through it all.

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DESCRIPTION OF THESIS STRUCTURE

The body of this thesis, *Effects of Subglottic Stenosis and Cricotracheal Resection on Voice Production in Women*, is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. This thesis is based on data from a larger multi-institutional project. Related publications will be submitted to peer-reviewed journals, with the author of this thesis included as one of multiple coauthors. The consent and authorization document is found in Appendix A and an annotated bibliography is presented in Appendix B.

Introduction

Subglottic stenosis (SGS) is a narrowing of the airway in the region of the cricoid cartilage below the vocal folds and above the tracheal rings (Conley, 1953). It is distinguished by location from other forms of airway stenosis such as that of the larynx or trachea, as well as other upper airway obstructions such as laryngomalacia and unilateral or bilateral vocal fold paralysis. Subglottic stenosis may be congenital or acquired, but specific causative factors are often unknown (Grillo, 1982). When it occurs at birth, SGS is often associated with genetic factors or syndromes. In contrast, acquired SGS may be associated with intubation, trauma, gastroesophageal reflux disease, or may occur with other chronic illnesses or autoimmune diseases such as Wegener's granulomatosis with microscopic polyangiitis, sarcoidosis, or systemic lupus erythematosus (Dedo & Catten, 2001; Maldonado et al., 2014; Rutter, Cohen, & de Alarcon, 2008; Valdez & Shapshay, 2002). Other risk factors for SGS include various types of respiratory infections and radiation at the level of the subglottis. Most individuals with SGS are female, perhaps due to the presence of estrogen and its relationship with airway irritation response mechanisms; however, many cases are also idiopathic (Damrose, 2008; Hseu, Benninger, Haffey, & Lorenz, 2014; Valdez & Shapshay, 2002).

Subglottic stenosis may be mistaken for other breathing disorders such as asthma, laryngomalacia, and paradoxical vocal cord dysfunction due to audible breathing patterns, often described as wheezing or stridor, as well as the presence of hoarseness (Maldonado et al., 2014). Endoscopic evaluation of the larynx and subglottis while the patient is symptomatic is essential for differential diagnosis. Treatment options for SGS vary depending on the level of severity, precise location and shape of the stenosis, and the presence of other health-related factors. Subglottic stenosis may be rated on a four-point grading scale, wherein grade one (I) indicates up

to 50% obstruction, grade two (II) being 51% to 70%, grade three (III) being over 70% obstruction but containing a detectible lumen, and grade four (IV) indicating no detectible lumen (Myer, O'Connor, & Cotton, 1994). Milder grades of SGS may be treated nonsurgically with pharmacological management such as proton-pump inhibitors to address reflux, or rheumatologic medications to address the underlying disease process. Moderate cases of SGS require medical management such as balloon dilation or endoscopic carbon dioxide laser procedures to remove excess airway tissue. However, severe cases of SGS, graded III or IV, require surgical management such as laryngotracheal or cricotracheal reconstruction (CTR) surgeries. Additionally, while early tracheal reconstruction surgeries have been reported since the 1950s (Conley, 1953), surgical procedures have evolved during the following decades.

Laryngotracheal resection involves splitting the cricoid cartilage and placing a stent to enlarge the airway at the level of stenosis, whereas CTR involves removal of the entire region of the stenosis and reconnecting the upper and lower portions of the airway via anastomosis (Hartley & Cotton, 2000). More recently, CTR has emerged as a potentially preferable method for treating SGS (Sandu & Monnier, 2008). Current CTR procedures typically involve the surgeon creating an anterior incision from the inferior surface of the thyroid cartilage down to the inferior portion of the stenotic region of the trachea. Then the surgeon makes lateral vertical incisions and horizontal incisions along the inferior border of the cricoid cartilage and the stenotic region, subsequently removing the stenotic portion of the trachea. The lateral and posterior portions of the cricoid remain intact but the anterior portion is removed. Finally, the patient's head is fixed in a flexed position as the lower healthy portion of the trachea is sutured up to the thyroid cartilage (Monnier, Lang, & Salvary, 1999; White & Rutter, 2009).

Although CTR has emerged as a promising surgical tool for managing SGS and minimizing the need for tracheostomy, CTR has been associated with negative effects on voice production (Bryans, Palmer, Schindler, Andersen, & Cohen, 2013; Ettema, Tolejano, Thielke, Toohill, & Merati, 2006; Grillo, Mathisen, Ashiku, Wright, & Wain, 2003; Houlton et al., 2011; MacArthur, Kearns, & Healy, 1994; Smith, Roy, Stoddard, & Barton, 2008). These negative consequences have included reduced fundamental frequency (F_0) range, lower mean habitual F_0 , reduced overall intensity, breathiness, hoarseness, inability to project the voice, and vocal strain. Although CTR is the primary treatment of choice for managing severe airway obstruction in SGS, it is valuable to understand the potentially adverse voice-related surgical effects. Understanding these effects might improve patient education prior to and following surgery, as well as possibly inform the development of novel surgical procedures to treat SGS with reduced negative vocal consequences. Additionally, some surgeons have elected to perform repeated balloon dilations versus CTR to avoid the potential for adverse voice effects.

Only a few studies have attempted to quantify the effects of SGS and CTR on voice production (Bryans et al., 2013; Ettema et al., 2006; Houlton et al., 2011; Hseu et al., 2014; Smith et al., 2008). Among these studies, videostroboscopic, laryngoscopic, aerodynamic, acoustic, and auditory-perceptual measures have been employed. Collectively, the results from these studies indicate that although airway patency increases with surgical management, voice quality decreases. As mentioned previously, lowered habitual F_0 appears to be one of the most notable postsurgical sequelae. However, the interpretation of these studies is somewhat complex, due to the variety of experimental methodologies, the small numbers and limited severity ranges of participants, and the specific voice measures employed.

Smith et al. (2008) examined the medical records of 14 women with idiopathic SGS who had undergone CTR at their facility within the previous five years. These authors examined voice outcomes by comparing presurgical and postsurgical recordings. Measures included maximum phonation time, F_0 during sustained /a/ vowel at a comfortable pitch and loudness, mean F_0 during oral reading of the Rainbow Passage (Fairbanks, 1960), and F_0 glides from the midrange to reported maximum and minimum F_0 on /a/. Among these measures, the mean F_0 during sustained /a/ and the Rainbow Passage, as well as F_0 glides were the most sensitive to postsurgical voice change. Smith et al. concluded that CTR has the potential to lower speaking F_0 significantly in women.

A subsequent study examined voice outcomes following CTR in 16 patients with SGS, including 15 females and one male (Houlton et al., 2011). A retrospective chart review was undertaken, which identified patients with SGS during the prior 10 years. Presurgical and postsurgical voice recordings were available for 7 of the 16 patients, with the remaining patients having had either presurgical or postsurgical recordings. Demographic data and surgical records were reported in addition to the following voice measures: maximum phonation time, mean F_0 during sustained /a/ vowels and the Rainbow Passage, mean intensity, F_0 glides from the midrange to the reported maximum and minimum F_0 on /a/, jitter, shimmer, harmonic-to-noise ratio, average subglottic pressure, average airflow during the sustained /a/ vowel, and the Consensus on Auditory-Perceptual Evaluation of Voice (CAPE-V; Kempster, Gerratt, Abbott, Barkmeier-Kraemer, & Hillman, 2009). Of the above measures, only mean F_0 during the sustained vowel and Rainbow Passage changed (i.e., decreased) significantly following CTR. The CAPE-V mean increased (i.e., worsened) from 27.8 to 47.5 on a 100-point scale after CTR, but increases were not statistically significant. In general, these results confirmed the findings of

Smith et al. (2008), namely that F_0 decreased postsurgically during sustained vowels and connected speech, but F_0 range was not reduced. Additionally, aerodynamic and intensity measures failed to demonstrate significant change after CTR. Importantly, however, CAPE-V auditory-perceptual data indicated overall voice severity prior to surgical management in this population.

More recently, Bryans et al. (2013) examined several subjective and quasi-objective parameters of voice production in women following either CTR or dilation. A total of 23 women were included in the study. The participants were divided into two groups, including those managed with CTR and those treated with tracheal dilation procedures. Measures included the Voice Handicap Index (Jacobsen et al., 1997), sustained vowels at the reportedly least and greatest possible intensities, ascending and descending F_0 glides, the Rainbow Passage, the CAPE-V, maximum phonation time, and mean F_0 calculations. Videolaryngostroboscopy was also implemented. Significant differences were observed between the CTR and dilation groups. Acoustically, the CTR group showed a significantly lower mean F_0 during sustained phonation, reduced maximum F_0 , and reduced intensity variation after surgery. Auditory-perceptual ratings of breathiness, pitch, and loudness were also significantly worse in the CTR group compared to the dilation group. Videolaryngostroboscopic analysis revealed that the CTR group had significantly poorer scores on phase symmetry, amount of ventricular fold movement, and hyperfunction during speech. The CTR group scored more poorly on the Voice Handicap Index in the total score and all subscales.

Most recently, Hseu et al. (2014) performed a 10-year retrospective chart review to examine Subglottic stenosis patient outcomes for endoscopic dilation and several associated procedures. The study included 92 adults, 69 females and 23 males, who collectively underwent

247 endoscopic dilations. SGS causative factors included Wegener's granulomatosis with microscopic polyangiitis, intubation, and idiopathic occurrences. The majority (i.e., 55%) of patients underwent multiple surgeries. The type of surgical management was not associated with the amount of time until the next required surgery. A subset of participants ($n = 44$) in this study received voice evaluations before and after surgery, including videolaryngostroboscopy, the Voice Handicap Index, and maximum phonation time. Interestingly, the Voice Handicap Index scores improved (i.e., decreased) from 39 to 18, and maximum phonation time improved from 14 to 21 seconds after surgery. These results were somewhat at odds with previous studies (Bryans et al., 2013; Smith et al., 2008) that observed worsening voice quality after surgery, although it should be noted that Hseu et al. (2014) did not include CTR as a surgical technique. It is possible that the lack of adverse findings related to postsurgical outcomes might also be moderated by the need for more frequent surgical management with dilation versus CTR; however, this study demonstrates the need for additional research in both presurgical and postsurgical SGS patient populations.

In general, the relatively few studies that have included voice assessment in presurgical and postsurgical patient populations indicate that voice problems might exist both before and after treatment in at least some patients with SGS. The impact of surgical management on these voice problems seems to vary depending on surgical technique, severity of the stenosis, and the specific measures used to quantify the dysphonia. The most consistent postsurgical voice problem reported in the literature is F_0 lowering (Bryans et al., 2013; Ettema et al., 2006; Houlton et al., 2011; Hseu et al., 2014; Smith et al., 2008), presumably due to cricothyroid muscle disturbance during surgery (Smith et al.). Research has also indicated that SGS is associated with presurgical voice disorders based on auditory-perceptual judgments (Ettema et

al., 2006). However, it is not entirely clear why SGS alone should be associated with voice disorders in individuals prior to surgical management.

To identify possible reasons why SGS alone might be associated with voice disorders, it is useful to consider existing theories regarding voice and resonance. The source-filter theory (Fant, 1970; Titze, 1994) suggests that the acoustic, auditory-perceptual, aerodynamic, and other physiologic features of voice and speech production are highly influenced by the relationship between the vibrating vocal folds (i.e., the sound source) and the supraglottic vocal tract (i.e., the filter). More recently, it has been theorized that changes in the shape of the supraglottic vocal tract might also influence the vocal fold vibratory source (Titze, 2001). Indeed, advancements in this theory have led to the development of the semi occluded vocal-tract theory and associated therapeutic techniques to treat voice disorders (e.g., Gaskill & Quinney, 2012; Guzman, Castro, Testart, Muñoz, & Gerhard, 2013; Patel, Pickering, Stemple, & Donohue, 2012). The primary tenet of the semi occluded vocal-tract theory is that supraglottic semi occlusion creates unique interactions with the vibrating source, thereby influencing vocal fold oscillation during sustained phonation and connected speech. Similarly, basic source-filter theory would also seem to suggest that the vocal fold vibratory source would also interact with the subglottic space, which in turn might influence subsequent vocal fold oscillations and voice quality (Sundberg, Scherer, Hess, Müller, & Granqvist, 2013). Therefore, from both theoretical and clinical perspectives, it is essential to quantify the effects of SGS across all surgical interventions, to inform patient education and hopefully the development of future treatments to manage both breathing and voice symptoms. Toward that long-term objective, this study examined audio recordings of individuals with SGS to address the following research aims:

1. To quantify the acoustic and auditory-perceptual features of SGS.
2. To examine possible acoustic and auditory-perceptual changes in voice production following CTR in a subset of patients with SGS.

Method

This study was part of a larger investigation of the influence of subglottic stenosis on voice production. Coinvestigators on this investigation consisted of the graduate thesis committee, including Kristine Tanner, Ph.D., Christopher Dromey, Ph.D., David McPherson, Ph.D., Jonathan Wisco, Ph.D., and Mark L. Berardi, B. S. (Brigham Young University, Provo, Utah), as well as Eric Hunter, Ph.D. (Michigan State University, East Lansing, Michigan), Scott Thomson, Ph.D., (Brigham Young University—Idaho, Rexburg, Idaho), and Marshall E. Smith, M.D. (The University of Utah, Salt Lake City, Utah). This study was funded by the National Institute on Deafness and Other Communication Disorders at the National Institutes of Health (R01 DC009616).

Participants

A retrospective chart review identified 28 adult females (ages 23 to 73 years; $M = 50.2$ years; $SD = 12.7$ years) with idiopathic SGS who received CTR at The University of Utah Voice Disorders Center between 2008 and 2014. Inclusion criteria consisted of the presence of SGS requiring surgical management, being over 18 years of age, and the availability of presurgical and/or postsurgical research-quality audio recordings suitable for acoustic analysis. Participants were excluded only if recordings were not research quality (i.e., significant background noise). Subglottic stenosis diagnosis was provided by Marshall E. Smith, MD, laryngologist at The University of Utah Voice Disorders Center, and was based on a combination of medical history, auditory-perceptual evaluation, videolaryngostroboscopy, bronchoscopy, and computerized

tomography (CT) scans. All participants had a previous history of microlaryngoscopy with dilation procedures performed by Dr. Smith. At the time of CTR, all presented with either Grade I or Grade II SGS. A revised CTR procedure aimed to minimize adverse voice effects was performed on all participants by Dr. Smith. All study-related procedures were approved by the Institutional Review Boards at The University of Utah (IRB#00045048) and Brigham Young University (IRB#E14524).

Speech Samples

Clinical speech samples were collected using research-quality recording equipment, including a (VIXIA HF S21 HD) Canon camcorder and a (Shure SM48; Shure, Niles) dynamic microphone at a sampling rate of 44.1 kHz (16 bit). The mouth-to-microphone distance was 4 inches. Presurgical samples were collected on average 37.8 days ($SD = 66.9$ days) prior to CTR postsurgical samples were collected approximately 189.4 days ($SD = 104.9$ days) following CTR on average. For purposes of the present investigation, speech stimuli included the Rainbow Passage (Fairbanks, 1960) and sustained /a/ vowels. Other speech tasks were sampled from participants, but were not collected frequently enough for inclusion in the present study. Therefore, 11 paired pre and postsurgical samples, as well as 6 presurgical samples and 9 postsurgical samples, were included in this study.

Original clinical recordings were de-identified at The University of Utah and extracted using Adobe Audition (version 3.0; Adobe, San Jose, California, USA). For purposes of acoustic and auditory-perceptual evaluation, the second and third sentences of the Rainbow Passage and the central three seconds of the sustained vowel were extracted at Brigham Young University using Audacity (v. 2.0.6; audacity.sourceforge.net, La Jolla, California) and resaved at 44.1 kHz (16 bit). Subsequent acoustic analyses were performed using this sampling rate, with the

exception of the Cepstral Spectral Index of Dysphonia (CSID™), periodicity, and F_0 analyses, which were automatically downsampled to 25 kHz within the Analysis of Dysphonia in Speech and Voice (ADSV™) and Multidimensional Voice Program (MDVP™) software packages (version 5109; KayPentax; Montvale, New Jersey, USA). Additionally, for purposes of auditory-perceptual analyses, speech samples were normalized for amplitude and saved as stereo files such that listeners could hear samples binaurally via headphones.

Acoustic Analysis Procedures

F_0 and voice signal periodicity measures were made using the MDVP program. Cepstral measures were computed using the ADSV program. Additional spectral analysis and F_0 variability measures were extracted with a custom Matlab application provided by Eric Hunter, Ph.D., (Michigan State University, East Lansing, Michigan). All acoustic analyses are described in detail below.

F_0 analysis. To quantify the relationship between F_0 and SGS, as well as possible changes following surgical management, two primary F_0 analyses were undertaken. First, mean F_0 during connected speech and sustained vowel samples was calculated. This measure was selected primarily due to previous research indicating that F_0 might decrease after SGS surgery due to possible negative effects on cricothyroid muscle activity (Smith et al., 2008). However, it is also possible that SGS itself might be related to presurgical changes in F_0 due to potential influence of the subglottis on vocal fold oscillation. Similarly, F_0 variation might be reduced following surgical management of SGS due to changes in cricothyroid function. Therefore, F_0 semitone standard deviation (STSD) during connected speech was also calculated. Periodicity measures, including percent jitter and percent shimmer from sustained vowel phonation were also determined.

Pitch strength analysis. In this context, pitch strength is a calculated estimation of the listener tonal auditory-perceptual correlates of a sound (Camacho, 2012). In other words, pitch strength estimates how a listener may judge the pitch saliency of a sound. Sound spectra that are characterized by more energy surrounding the F_0 and harmonics are associated with greater pitch strength. So as pitch strength increases, the spectral slope also increases. Pitch strength has also been shown to correlate with auditory-perceptual judgments of tonality of sound samples (Shrivastav, Eddins, & Anand, 2012). Additionally, calculated pitch strength has been shown to correlate with the vibratory types associated with voice production (Kopf et al, 2014). Because patients with SGS can sound breathy, it is reasonable that pitch strength might improve as breathiness decreases.

Cepstral analysis. Recent literature indicates that cepstral characteristics of the acoustic voice sample are significantly associated with perceptual ratings of voice disorder severity (Awan, Roy, & Dromey, 2009; Peterson et al., 2013). Because individuals with SGS might have voice disorders both prior to and following surgical management, the present study attempted to quantify acoustic voice disorder severity in presurgical and postsurgical voice samples. Fourier transform of a Fourier transform generates the cepstral spectrum, with the cepstral peak prominence (CPP) highly correlated with voice disorder severity. Cepstral peak prominence, along with the cepstral slope and central tendency parameters—similar to moments of the long-term average spectrum—are used to calculate the CSID. To that end, CPP and variation measures were calculated to generate the CSID for connected speech and sustained vowel samples.

Auditory-Perceptual Analysis Procedures

Because individuals might experience voice changes that have unique auditory-perceptual features, which are possibly distinct from acoustic features of voice production, auditory-perceptual analysis of presurgical and postsurgical speech samples was undertaken. Auditory-perceptual analyses were performed by 13 graduate students in the Department of Communication Disorders at Brigham Young University, all of whom had taken the graduate voice disorders course from Kristine Tanner, Ph.D. (Brigham Young University, Provo, Utah). Although the target number of listeners for this study was 10, auditory-perceptual ratings were oversampled in case some listeners proved unreliable in their ratings and thus would necessarily be excluded from statistical analysis. All listeners passed a standard hearing screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz.

Listener tasks included ratings of (a) overall voice severity, (b) monotonicity, and (c) overall F_0 increase, decrease, or no change (i.e., a rating task for randomized pretreatment and posttreatment pairs only). Prior to initiation of the listening task, listeners were oriented to a range of voice disorder severity (i.e., from normal to severe) for the Rainbow Passage and sustained vowels, and listeners practiced the rating tasks. Once the listening experiment was initiated, 10% of samples were randomly repeated to estimate intrajudge reliability. Each of the three listening tasks was performed separately, such that listeners rated voice severity for all connected speech and sustained vowel samples prior to proceeding to monotonicity and F_0 change ratings. Both voice severity and monotonicity ratings were performed using an approximately 10 cm visual analog scale (VAS), with an interactive computer program permitting a cursor to be placed at any point on the scale, the extreme left indicating normal voice or no monotonicity, and the extreme right indicating extreme voice disorder severity or

monotonicity. The third listening task applied to pre and posttreatment sample pairs only, and consisted of a three-item response indicating the auditory-perceptual judgment of overall F_0 increase, decrease, or no change for connected speech and sustained vowel samples. All ratings were accomplished via a custom Matlab computer program created by Christopher Dromeey, Ph.D. (Brigham Young University, Provo, Utah). All listening tasks were accomplished in a single-walled sound booth while listeners wore Sennheiser (HD 558) headphones. Listeners were permitted to adjust sample presentation to a comfortable loudness level, and were able to repeat sample presentations as many times as desired prior to moving to the next sample or sample pair.

Statistical Analysis

Descriptive summary statistics were used to examine acoustic and auditory-perceptual measures for all connected speech and sustained vowel samples. Intraclass correlation coefficients were computed to determine interjudge agreement among listeners; Pearson correlations were used to determine intrajudge reliability. For pretreatment and posttreatment comparisons, paired samples t tests were performed. For samples provided by different pretreatment or posttreatment participants, independent samples t tests were performed. Bonferroni corrections were employed to account for multiple comparisons.

Results

Acoustic and auditory-perceptual data met the assumptions for parametric statistical analysis based on Levene's Test for Equality of Variances and examination of central tendency for sample groups. Therefore, two-tailed t tests were employed to examine differences between groups based on dependent variables, using a Bonferroni correction for multiple comparisons and an alpha level of .05. Specifically, independent samples t tests were performed for patients who provided only pretreatment ($n = 6$) or posttreatment ($n = 9$) samples and paired samples t

tests were performed for patients who provided both pretreatment and posttreatment ($n = 11$) samples.

Acoustic Analyses

Aggregate results for F_0 , periodicity, pitch strength, and cepstral measures for all sample groups are presented in Table 1. The results from independent samples t tests indicated no significant differences between samples from patients who provided only pretreatment ($n = 6$) or posttreatment ($n = 9$) recordings (Bonferroni correction $.05/9 = .005$). Specifically, the following values were observed: mean F_0 during sustained vowel phonation, $t(13) = 1.28, p = .222$; jitter %, $t(13) = 1.09, p = .294$; shimmer %, $t(13) = .084, p = .934$; CPP for sustained vowel phonation, $t(13) = -.739, p = .473$; CPP for connected speech, $t(13) = -1.306, p = .214$; CSID for sustained vowel phonation, $t(13) = .711, p = .490$; CSID for connected speech, $t(13) = 1.756, p = .103$; pitch strength, $t(13) = -1.278, p = .224$; and STSD, $t(13) = -2.382, p = .033$.

Table 1

Acoustic Measures of Voice Disorder Severity for Aggregate Participant Groups

Acoustic Variable	Mean (<i>SD</i>)	Min	Max	Normative Mean (<i>SD</i>)
Mean Fundamental Frequency (Vowel)				
Presurgical group	211.5 (43.9)	116.8	279.1	244.0 (27.5)
Postsurgical group	220.1 (63.9)	84.4	339.3	
Jitter, % (Vowel)				
Presurgical group	1.8 (1.4)	.3	5.6	.6 (.4)
Postsurgical group	1.8 (2.5)	.3	10.0	
Shimmer, % (Vowel)				
Presurgical group	5.7 (3.7)	2.1	15.7	2.0 (.79)
Postsurgical group	5.6 (5.4)	1.4	22.1	
Cepstral Peak Prominence (Vowel)				
Presurgical group	8.8 (2.1)	3.3	13.4	--
Postsurgical group	9.6 (3.2)	.2	13.6	
Cepstral Peak Prominence (Rainbow)				
Presurgical group	5.4 (1.4)	2.0	7.2	--
Postsurgical group	5.5 (1.2)	2.9	7.2	
Cepstral Spectral Index of Dysphonia (Vowel)				
Presurgical group	31.9 (35.7)	-7.7	153.9	--
Postsurgical group	18.2 (18.3)	-9.1	60.6	
Cepstral Spectral Index of Dysphonia (Rainbow)				
Presurgical group	30.5 (23.4)	1.2	76.4	--
Postsurgical group	25.8 (17.5)	-0.4	63.8	
Pitch Strength (Vowel)				
Presurgical group	39.5 (10.6)	19.9	54.3	--
Postsurgical group	42.4 (14.0)	0.0	56.2	
Semitone Standard Deviation (Rainbow)				
Presurgical group	2.2 (.5)	1.3	3.0	--
Postsurgical group	2.6 (.9)	1.2	4.7	

Note. The presurgical and post-surgical groups above included patients who provided both pre and post recordings ($n=11$) as well as patients who provided only pre ($n=6$) or post ($n=9$) recordings.

The results from paired-samples t tests for the 11 patients who provided both pretreatment versus posttreatment sample groups are presented in Table 2. Again, no significant differences were observed between pre and postsurgical recordings (Bonferroni correction $.05/9 = .005$). The following values were observed: mean F_0 during sustained vowel phonation, $t(10) = .927, p = .376$; jitter %, $t(10) = -.649, p = .531$; shimmer %, $t(10) = -.161, p = .875$; CPP for sustained vowel phonation, $t(10) = -.427, p = .678$; CPP for connected speech, $t(10) = .829, p = .426$; CSID for sustained vowel phonation, $t(10) = 1.115, p = .291$; CSID for connected speech, $t(10) = -.482, p = .640$; pitch strength, $t(10) = .062, p = .952$; and STSD, $t(10) = .125, p = .903$. To compare this data set with previous SGS treatment studies, select variables are illustrated. For the 11 pretreatment and posttreatment sample groups, mean F_0 during sustained phonation is illustrated in Figure 1. CSID and STSD are illustrated in Figures 2 and 3, respectively.

Table 2

*Acoustic Measures of Voice Disorder Severity for Pretreatment versus Posttreatment Participant**Groups*

Acoustic Variable	Mean (SD)	Min	Max	Normative Mean (SD)
Mean Fundamental Frequency (Vowel)				
Presurgical group	214.9 (39.8)	153.3	278.3	244.0 (27.5)
Postsurgical group	201.0 (64.8)	84.4	311.8	
Jitter, % (Vowel)				
Presurgical group	2.2 (1.6)	.6	5.6	.6 (.4)
Postsurgical group	2.6 (3.2)	.4	10.0	
Shimmer, % (Vowel)				
Presurgical group	6.6 (4.2)	2.4	15.7	2.0 (.79)
Postsurgical group	6.8 (7.0)	1.4	22.1	
Cepstral Peak Prominence (Vowel)				
Presurgical group	8.2 (2.1)	3.3	10.6	--
Postsurgical group	8.6 (3.7)	.2	13.0	
Cepstral Peak Prominence (Rainbow)				
Presurgical group	5.8 (1.5)	2.0	7.2	--
Postsurgical group	5.6 (1.4)	2.9	7.2	
Cepstral Spectral Index of Dysphonia (Vowel)				
Presurgical group	41.0 (40.8)	11.3	153.9	--
Postsurgical group	24.6 (21.0)	-5.8	60.6	
Cepstral Spectral Index of Dysphonia (Rainbow)				
Presurgical group	23.9 (23.7)	1.2	76.4	--
Postsurgical group	25.5 (18.6)	-0.4	58.0	
Pitch Strength (Vowel)				
Presurgical group	38.1 (10.8)	19.9	50.1	--
Postsurgical group	38.0 (16.9)	0.0	54.7	
Semitone Standard Deviation (Rainbow)				
Presurgical group	2.2 (.5)	1.4	3.0	--
Postsurgical group	2.2 (.8)	1.2	4.2	

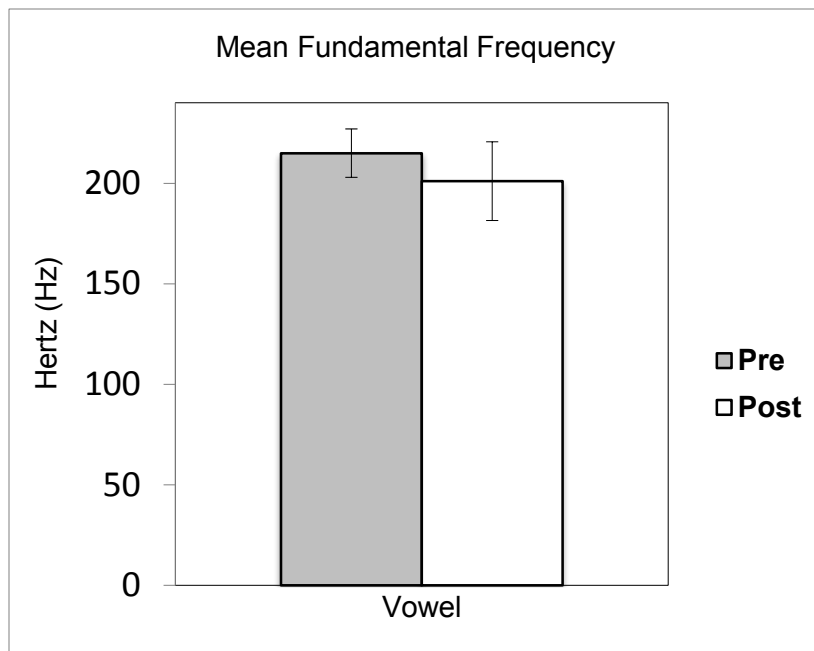


Figure 1. Means and standard error bars for pretreatment versus posttreatment mean fundamental frequency (F_0).

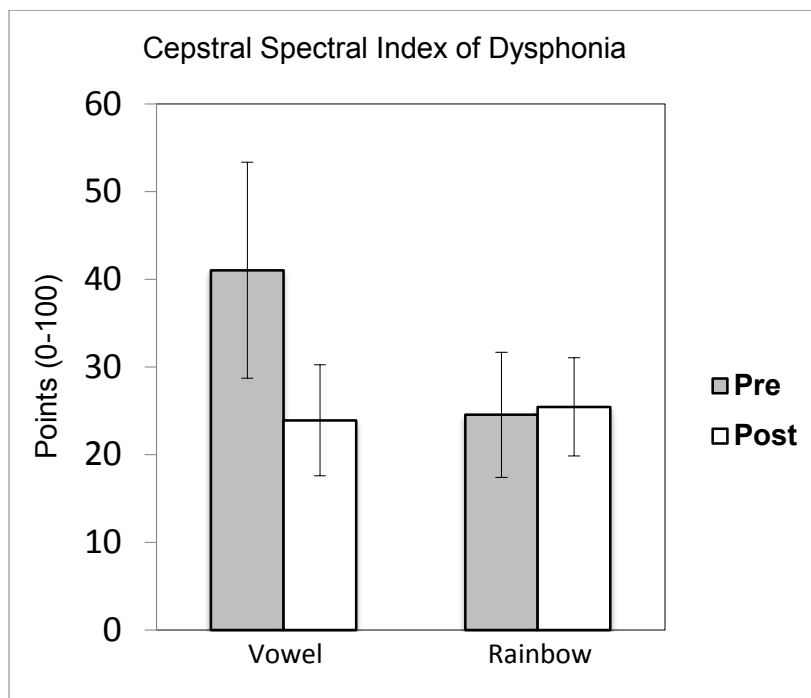


Figure 2. Means and standard error bars for pretreatment versus posttreatment voice disorder severity based on the cepstral-spectral index of dysphonia (CSID).

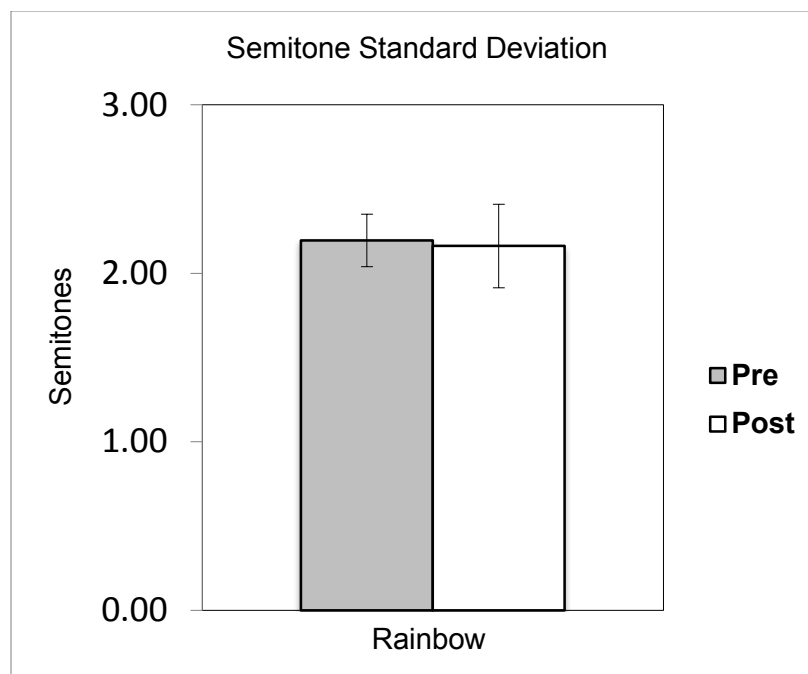


Figure 3. Means and standard error bars for pretreatment versus posttreatment semitone standard deviation (STSD).

Auditory-Perceptual Analyses

Upon examination of the auditory-perceptual data set provided by the graduate student raters, 11 of the 13 original graduate student raters met inclusion criteria based on a Pearson r correlation of .89 for repeated ratings of 10% of the samples. For those 11 raters, the single measures Intraclass Correlation Coefficient was .701 and the average measures Intraclass Correlation Coefficient was .963, $F(26, 260) = 26.808$, $p < .001$, indicating acceptable agreement among raters. Therefore, ratings from those 11 individuals were averaged and included in the auditory-perceptual analysis.

Data from patients who provided only pretreatment ($n = 6$) or posttreatment ($n = 9$) samples were analyzed using independent samples t tests (Bonferroni correction $.05/3 = .016$). No significant differences were observed. Specifically, mean connected speech voice severity ratings were 19.9 ($SD = 14.8$) of 100 points for pretreatment samples and 12.8 ($SD = 15.1$) of

100 points for posttreatment, $t(13) = .898, p = .386$. Mean connected speech voice monotonicity ratings were 17.9 ($SD = 12.1$) of 100 points for pretreatment samples and 13.0 ($SD = 20.4$) of 100 points for posttreatment, $t(13) = .533, p = .603$. Mean sustained vowel voice severity ratings were 28.0 ($SD = 17.5$) of 100 points for pretreatment samples and 12.9 ($SD = 7.9$) of 100 points for posttreatment, $t(13) = 2.295, p = .039$.

Data from patients who provided both pretreatment and posttreatment samples ($n = 11$) were analyzed using paired samples t tests (Bonferroni correction $.05/3 = .016$). No significant differences were observed. Specifically, mean connected speech voice severity ratings were 16.8 ($SD = 11.9$) of 100 points for pretreatment samples and 15.5 ($SD = 15.5$) of 100 points for posttreatment, $t(10) = .302, p = .769$. Mean connected speech voice monotonicity ratings were 19.3 ($SD = 8.7$) of 100 points for pretreatment samples and 23.3 ($SD = 16.0$) of 100 points for posttreatment, $t(10) = -.888, p = .395$. Mean sustained vowel voice severity ratings were 36.5 ($SD = 23.2$) of 100 points for pretreatment samples and 33.5 ($SD = 29.4$) of 100 points for posttreatment, $t(10) = .510, p = .621$.

For the 11 patients who provided pretreatment and posttreatment samples, auditory-perceptual judgments of pitch change after CTR were undertaken. Ordinal data were collected including ratings of no change, pitch increase, or pitch decrease. When the raters' judgments were averaged, 53.7% of presented sample pairs were judged to decrease in pitch from pretreatment to posttreatment; 36.4% of sample pairs were judged to stay the same and 9.9% were judged to increase in pitch from pretreatment to posttreatment.

Discussion

The purpose of the present investigation was twofold: to quantify the acoustic and auditory-perceptual features of SGS and to examine possible changes in these features following

CTR. Participants included a subset of adult female patients from a single laryngology practice who received a CTR surgical procedure to address idiopathic SGS. All participants had received a prior microlaryngoscopy and balloon dilation procedure with subsequent recurrence to grade I or II subglottic narrowing. For purposes of this study, recordings were retrieved from a clinical audio archive from patients with either pretreatment or posttreatment samples, as well as patients who provided both pretreatment and posttreatment samples. In general, analysis of the results indicated that these pretreatment SGS patients demonstrated mild to mild-to-moderate voice disorder severity based on both acoustic and auditory-perceptual ratings. Neither acoustic nor auditory-perceptual voice disorder severity measures significantly worsened following the CTR procedure. Auditory-perceptual ratings of pitch change indicated that the majority of participants decreased in pitch from pretreatment to posttreatment, but not significantly so. These findings indicate that the revised CTR procedure might be a viable alternative to less permanent subglottic dilation procedures, with minimal adverse effects on voice quality.

Studies related to preintervention voice function in patients with SGS indicate that voice disorders are relatively common in this population. Yet only a few studies have attempted to quantify the nature and severity of these voice disorders, including both perceptual and objective measures, prior to surgical management. The majority have included patient self-report as the primary outcome variable for examining voice function at baseline. Recently, Hseu et al. (2014) observed mild to mild-to-moderate voice severity in a subset of patients with SGS prior to surgery based on self-report ratings from the VHI. Smith et al. (2008) also observed voice disorders in the mild-to-moderate range based on selected acoustic measures prior to surgical management of idiopathic SGS in a similar group of patients to those in the present study. Most recently, Hoffman, Brand, and Dailey (2015) performed a study of 10 patients with SGS who

ultimately received balloon dilation as an alternative to the potentially more detrimental effects of open laryngeal surgeries such as CTR. The authors documented presurgical voice disorder severity in the very mild range based on the VHI and the severe range based on the auditory-perceptual GRBAS scale (G = grade, R = roughness, B = breathiness, A = asthenia, S = strain; Hirano, 1981). The authors concluded that additional studies were needed to document voice disorders in this population, including treatment response.

The findings from the present study are consistent with those documenting a mild to moderate voice disorder in patients with SGS whose stenosis was severe enough to warrant surgical intervention. Some variability in findings among studies might be explained by differences in the measurement tool used, sampling techniques, patient instructions, and methods for analysis. For example, it is possible that patients tend to underestimate their voice disorder severity based on dyspnea symptoms that might eclipse or interact with voice concerns. This could explain why examiner-based and objective measurement tools seem to indicate greater voice disorder severity in this population. Regardless of these possible reasons for variability across studies, the results from the present investigation indicate that patients with SGS present with voice disorder severity ranging from mild to moderate based on auditory-perceptual, aerodynamic, and acoustic analyses. Presumably, the greater the severity of the stenosis, the more severe the voice disorder; however, this is yet to be proven because many patients seek out and receive surgical intervention in the form of balloon dilation prior to open laryngeal procedures (Hoffman et al., 2015).

Currently, balloon dilation procedures have become the more commonly used interventions in managing SGS. This shift in clinical practice seems to relate to both the negative impact of more invasive surgical procedures such as SGS on voice function, as well as the less

invasive nature of microlaryngoscopy dilation procedures. Hoffman et al. (2015) reported improved VHI and Dysphonia Severity Index (Wuyts et al., 2000) scores, reduced acoustic voice severity, and improved glottal function postdilation. In other recent work, the effects of balloon dilation were compared between patient groups with laryngotracheal versus SGS. The authors documented that voice disorders were significantly more severe in laryngotracheal or multilevel stenoses, whereas SGS patients presented with more mild voice problems. This study found that patient-reported voice-related quality of life (V-RQOL; Kupfer, Hogikyan, & Hogikyan, 2014) improved postdilation in patients with SGS versus other stenoses of the airway. Similar findings were observed by Hatcher, Dao, and Simpson (2015). Unfortunately, dilation procedures are not long-lasting, with many patients having to return within one year for a repeated procedure. In some cases, multiple dilations result in a lengthier period of airway patency, but this result varies. Therefore, the advantages of a less invasive dilation procedure resulting in improved airway patency and voice function are often offset by the transiency of the improvement and likelihood of recurrence.

In the present investigation, no significant worsening was observed following the more invasive revised CTR procedure specifically performed to preserve cricothyroid function. Further, although mean F_0 did decrease posttreatment, it remained within normal limits. Additionally, the finding that STSD did not change from pretreatment to posttreatment is particularly interesting given that previous versions of the CTR procedure affected the cricothyroid musculature, resulting in a more monotone voice. The results from this investigation indicate that, although F_0 decreased slightly posttreatment, this change was not significant and did not influence the patient's ability to produce prosodic changes during connected speech sampling (i.e., during oral reading of the Rainbow Passage) based both on auditory-perceptual

and acoustic analyses. These findings indicate that posttreatment changes in voice quality are likely to exclude prosodic limitations, thus resulting in a more favorable surgical outcome. Future studies, such as randomized experimental trials, are warranted to determine which surgical management procedures produce the most successful outcomes for both voice function and sustained airway management.

Several caveats should be considered when examining the results from the present investigation. First, the sample size in this study was somewhat low, thus minimizing statistical power and the ability to detect subtle differences between groups or following surgery. Although SGS is a relatively rare condition, larger sample sizes are needed to more thoroughly evaluate differences in voice and airway outcomes. Ultimately, multi-center, blinded, randomized clinical trials will be required to evaluate which surgical procedures provide the optimal outcome for this patient population. Second, it should be noted that the recordings in the present study were obtained in a clinical setting; thus, additional potentially useful tasks such as pitch glides were not obtained. Despite this limitation, STSD did not change from pretreatment to posttreatment, indicating that cricothyroid function for the speaking voice was likely preserved following the revised CTR procedure. Additionally, a few patient samples contained vocal fry posttreatment, influencing interpretation of the results related to possible F_0 change after surgery. Although there are several possible reasons why patients might use vocal fry following surgery but not before (e.g., changes in respiratory patterns for speech), this should be considered when examining postsurgical F_0 in this study population. Future studies might be designed to control for patients' productions, including instructions to avoid vocal fry during voice sampling. Future studies should consider these points when examining treatments for this population.

In summary, this study examined the effects of a revised CTR procedure on voice production in SGS. The results indicated that this procedure was effective in preserving voice function while producing the desired airway patency outcomes. Future studies should examine this CTR procedure as compared to other treatments to determine the best methods for preserving voice function while managing the airway. Additionally, research involving the causative factors for voice disorders in this population is important to inform novel treatment development. The cost-benefit ratio between the less invasive balloon dilation procedure and revised CTR should be examined with respect to invasiveness of the procedure and the permanence of the surgical result.

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Appendix A

Consent and Authorization Document

Consent to be a Research Subject

Introduction

This research study is being conducted by **Kristine Tanner** at Brigham Young University to determine **the presence or absence and severity of voice problems in individuals with subglottic stenosis**. You were invited to participate because **you are a graduate student in Communication Disorders at Brigham Young University who is familiar with rating scales and the range and severity of voice disorders**.

Procedures

This is a listening experiment. You will listen to de-identified recordings of people with subglottic stenosis and will rate the presence or absence and severity of voice disorders in these individuals. You will also indicate if speaking pitch increased, decreased, or stayed the same based on pairs of recordings.

If you agree to participate in this research study, the following will occur:

- you will received a hearing screening (10 min)
- listen to a few sample voices to orient you to the task and to practice (5 min)
- listen to and rate connected speech samples of individuals with subglottic stenosis (20 min)
- listen to and rate sustained vowel samples of individuals with subglottic stenosis (20 min)
- choose if paired voice sample speaking pitch increased, decreased, or stayed the same (30 min)
- total time commitment will be approximately 120 minutes

This research will take place in 106 John Taylor Building (TLRB) at Brigham Young University.

Risks/Discomforts

You may become fatigued or need a break during the experiment. If this occurs, please alert the researcher and you will be given break time as needed.

Benefits

There will be no direct benefits to you. It is hoped, however, that through your participation researchers may learn about voice disorders in people with subglottic stenosis.

Confidentiality

Your ratings are confidential. Your ratings will be assigned a number and will never be associated with your name. All ratings are stored on a password-protected laboratory computer with restricted access.

Compensation

You will receive \$30 for your participation; compensation will not be prorated.

Participation

Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

Questions about the Research

If you have questions regarding this study, you may contact Kristine Tanner, Ph.D. at (801) 422-7045 for further information.

Questions about Your Rights as Research Participants

If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Statement of Consent

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): _____ Signature _____ Date: _____

Appendix B

Annotated Bibliography

Bryans, L., Palmer, A. D., Schindler, J. S., Andersen, P. E., & Cohen, J. I. (2013). Subjective and objective parameters of the adult female voice after cricotracheal resection and dilation. *Annals of Otolaryngology, Rhinology, & Laryngology*, *122*, 707-716.
doi: 10.1177/000348941312201108

Purpose: This study examined and compared the subjective and objective characteristics of the adult female voice after CTR or dilation. *Method:* A total of 23 female patients were included in this study, including 11 patients who had undergone CTR and 12 patients who had received a dilation procedure. Measurements taken from both groups included the Voice Handicap Index, sustained vowels at the highest and lowest intensities, F₀ glides from lowest to highest F₀ and comfortable F₀ to lowest F₀ connected speech sample using the Rainbow Passage, CAPE-V, flexible fiber optic or flexible distal chip videolaryngostroboscopic evaluations, maximum phonation time and minimum F₀. *Results:* Significant differences were found between the CTR and dilation groups on all measures. Acoustically, the CTR group showed a significantly lower mean F₀ on sustained phonation, reduced maximum F₀, a reduced pitch range, and a restricted ability to produce a quiet and a loud vocalization. Auditory-perceptual ratings of breathiness, pitch, and loudness were also significantly worse in the CTR group compared to the dilation group. Videolaryngostroboscopic analysis revealed the CTR group as having significantly worse scores in regard to phase symmetry, amount of ventricle fold movement, and hyper function during speech. The CTR group also scored worse on the Voice Handicap Index, including significantly higher scores on all three subscales as well as the total score. *Conclusions:* CTR does create long-term negative changes in the adult female voice. *Relevance to current work:* This study had many similarities to the current study, including participants, types of measurements, and objectives. The findings of this study serve as an excellent reference to what research exists in this area and what warrants further support and investigation.

Ching, H. H., Mendelsohn, A. H., Liu, I. Y., Long, J., Chhetri, K., & Berke, G. S. (2015). A comparative study of cricotracheal resection and staged laryngotracheoplasty for adult subglottic stenosis. *Annals of Otolaryngology, Rhinology & Laryngology*, *124*, 326-333.
doi: 10.1177/0003489414554942

Purpose: This study aimed to compare the applications and outcomes of two open airway surgical techniques, cricotracheal resection (CTR) and laryngotracheoplasty (LTP), used to remediate severe subglottic stenosis (SGS). *Methods:* Data were obtained retrospectively from a tertiary academic institution. Patients with SGS having undergone LTP or CTR were included, but those with a history of head or neck malignancy or stenosis without cricoid involvement were excluded. *Results:* The data for 61 LTP patients and 20 CTR patients were reviewed and compared. Significant associations between stenosis grade and decannulation were found in the LTP group (P = .01) but not in the CTR group. However, CTR patients achieved a 90% decannulation rate, whereas LTP patients achieved 80.3% at last follow up. Significant differences in stenosis etiology between LTP and CTR patients was found (P = .014). *Conclusions:* Stenosis grade and etiology should both be considered when determining specific surgical intervention for SGS. Both LTP and CTR have been shown effective and achieved high

decannulation rates. *Relevance to current study:* With such high decannulation rates and excellent airway management being achieved through a variety of surgical interventions it is time to consider the secondary effects of these surgical interventions and determine how the vocal quality of the patient can be preserved and or improved without compromising surgical success. The current study examines the effect of SGS on the adult female voice after CTR.

Conley, J.J. (1953). Reconstruction of the subglottic air passage. *Annals of Otolaryngology, Rhinology, & Laryngology*, 62, 477-495.

Review Article: The purpose of this article was to describe subglottic stenosis (SGS) and the possible treatments. Six different treatment techniques were described and illustrated in detail. Six case studies were used to demonstrate each therapeutic technique. The six different techniques discussed were as follows: dilation, free graft only, free graft and stent, direct approximation, utilization of mucoperichondrial flap, and reconstruction of the trachea. The purpose of, instructions on how to perform each, and the outcomes of each technique were described in detail. Some important descriptions discussed pertaining to the current study include the symptoms of SGS, the surgical outcomes of reconstruction (which is similar in nature to the cricotracheal resection used today) and descriptions of patient vocal quality posttreatment.

Damrose, E. J. (2008). On the development of subglottic stenosis. *Medical Hypothesis*, 71, 122-125. doi: 10.1016/j.mehy.2007.12.017

Review Article: This review article defines idiopathic SGS and describes the demographic of people most affected by it. Then the authors discuss their hypothesis for a possible etiology of idiopathic SGS. Their hypothesis is that idiopathic SGS is caused by severe coughing episodes that then create a detrimental chain reaction. The coughing leads to elevated subglottic pressure and constriction of the first tracheal ring, which then telescopes up into the cricoid cartilage. This is followed by mucosal edema, trauma to the cricoid mucosa, and reduced blood supply to the cricoid cartilage. Next inflammation sets in and possibly ischemia. The chain reaction ends with fibrosis and SGS, which is then exacerbated by an abnormal reaction to estrogen receptors until medical intervention is required. This hypothetical etiology for idiopathic SGS is important because it shows the possibility of serious disruption of the subglottis and larynx, which could easily impact the voice prior to any surgical management.

Dedo, H. H., & Catten, M. D. (2001). Idiopathic progressive subglottic stenosis: Findings and treatment in 52 patients. *Annals of Otolaryngology, Rhinology, & Laryngology*, 110, 305-311. doi: 10.1177/000348940111000403

Purpose: The purpose of this study was to report the clinical features and surgical management results of adult patients with idiopathic progressive SGS. *Method:* A retrospective chart review of 52 patients with idiopathic progressive SGS was performed. Information extracted from the medical charts included age, gender, measurements of the stenosis, nature and duration of symptoms, presence or requirement of tracheostomies, number and type of operations performed, time of follow-up, the presence of potentially related illnesses such as gastroesophageal reflux disease, and the presence of estrogen receptors in the submucosal connective tissue. *Results:* Patients with idiopathic progressive SGS included 51 females and one

male with a mean age of 43.5 years. Dyspnea or noisy breathing was a presenting symptom in about half the patients. None of the patients had a history of prolonged intubation or cervical trauma. Thirty-one patients reported no reflux complaints. Of the patients treated with antireflux medications none received any improvement. Four types of SGS were identified, type three being the most common (i.e., 39 patients). There was no systemic illness identified as a major contributing factor. Of the patients tested for elevated estrogen receptors, none were positively identified. *Conclusions:* The cause of idiopathic progressive SGS is still entirely unknown. Multiple different surgeries are commonly used to treat idiopathic progressive SGS but none cure it. All patients experienced recurrent stenosis postsurgery and required follow up surgeries. The least invasive, least expensive, and most successful suggested surgery is the laser submucosal resection with mucosal rotation flaps. *Relevance to current work:* This study provided a deeper understanding of the nature and characteristics of one type of SGS. It identified that patients had audible noisy breathing or dyspnea at baseline, which, if it had been tested, could potentially negatively affect the voice as well.

Ettema, S. L., Tolejano, C. J., Thielke, R. J., Toohill, R. J., & Merati, A. L. Perceptual voice analysis of patients with subglottic stenosis. *Otolaryngology—Head and Neck Surgery*, 135, 730-735. doi: 10.1016/j.otohns.2006.06.1249

Purpose: The characterization of perceptual voice abnormalities and identification of potential risk factors for perceptual voice abnormalities in patients with SGS were the objectives of this study. *Method:* Medical records of 31 patients (22 females, 9 males) with SGS from a three-year period at a single academic center were retrospectively reviewed. The Grade, Roughness, Breathiness, Asthenia, and Strain scale (Hirano, 1981), a widely used and accepted four point auditory-perceptual evaluation tool for grading overall vocal quality, was administered to each patient during their initial clinic visit to identify possible relationships between patient characteristics. Audio recordings from patients with SGS as well as patients with benign vocal disorders were used for comparison and intra-rater reliability and were statistically analyzed. *Results:* Average baseline data for all patients was $G_{1.4} R_{1.2} B_{0.5} A_{0.5} S_{1.1}$. Average male Grade scores were worse than females. Patients with multi-stenosis scored worse than patients with single-stenosis in Grade, Breathiness, and Asthenia. Grade, Roughness, and Breathiness scores were worse in patients without any prior airway surgery. Collectively patients never having had airway surgery had perceptually better voices across all categories. A higher likelihood of moderate or extreme dysphonia in the categories of GBS were associated with patients affected with vocal fold motion impairment. *Conclusions:* The Grade, Roughness, Breathiness, Asthenia, and Strain scale results indicated that collectively patients were perceived to have a mild to moderate dysphonia. Significant voice quality differences were noted between patients with multiple-site and single-site stenoses. Patients who had previous stenosis surgery had worse voice quality than those who had not undergone any previous surgery and had normal vocal fold motion. *Relevance to current work:* This study is important because it indicates that patients presented with mild to moderate dysphonia at baseline. This indicates that both SGS and CTR have an effect on the voice

Gelbard, A., Francis, D. O., Sandulache, V. C., Simmons, J. C., Donovan, D. T., & Ongkasuwan, J. (2015). Causes and consequences of adult laryngotracheal stenosis. *Laryngoscope*, *125*, 1137-1143. doi: 10.1002/lary.24956

Purpose: The aim of this study was to determine if laryngotracheal stenosis (LTS) is heterogeneous when considering clinical outcome, natural history, and etiology. *Methods:* The aim of this study was accomplished through a retrospective cohort study design using adult patients with LTS between the years 1998 and 2013. Specific patient characteristic information was recorded, including gender, age, race, comorbidities, and follow-up duration. Extracted information included etiology of stenosis, surgical dates, treatment approach, and if a tracheostomy was present at last follow-up. *Results:* Etiologies were determined to group into four categories; iatrogenic (54.7%), idiopathic (18.5%), autoimmune (18.5%), and traumatic (8%). Iatrogenic and autoimmune etiologies caused significantly more patients to remain tracheostomy-dependent in comparison to traumatic or idiopathic. *Conclusions:* LTS is heterogeneous in nature, stemming from multiple etiologies with different rates of long-term tracheostomy dependence. *Relevance to current study:* LTS is closely related to subglottic stenosis in that it affects the same anatomical structures as well as further down into the trachea and further up into the larynx. This article provides insight to the complex and diverse nature of LTS as a medical condition.

George, M. & Monnier P. (2010). Long-term voice outcome following partial cricotracheal resection in children for severe subglottic stenosis. *International Journal of Pediatric Otorhinolaryngology*, *74*, 154-160. doi: 10.1016/j.ijporl.2009.10.026

Purpose: This study examined the association between the presurgical glottic involvements of children with SGS and their postoperative voice following a partial cricotracheal resection (PCTR) based on a patient/parent proxy voice questionnaire. The hypothesis that patients with SGS who had vocal fold involvement would experience an impaired vocal quality post resection and anastomosis, and that those without vocal fold involvement would be expected to have normal vocal quality was also tested. *Methods:* Retrospective analysis of patient records spanning a 30-year period from a Swiss University Hospital was used in an interobserver study involving two ENT surgeons. The ENT's were required to independently rate the extent of SGS in 108 patients who had undergone PCTR based on a dynamic functional airway assessment and endoscopic images being totally blinded to one another's interpretations. According to the observations, the following four categories were created to describe glottic involvement: A. SGS clear from vocal folds (3-4 mm below vocal folds), B. SGS reaching the free boarder of vocal fold and/or the posterior commissure with slightly limited abduction with no true posterior glottis stenosis, C. SGS with associated posterior glottis stenosis or vocal fold fusion without cricoarytenoid ankylosis, D. Transglottic stenosis with/without bilateral cricoarytenoid ankylosis. A parent/patient proxy questionnaire was also given in order to evaluate the patients vocal functioning. *Results:* Of the 108 original patients, 77 remained available for long-term follow-up. Thirty-one patients were categorized as group A, 30 fell into group B, 12 went to group C, and 4 were put in group D. Patient/parent questionnaire results indicated only 18% of patients voices following PCTR were perceived as normal. Any patients with voices perceived as normal belonged to group A. Patients with mild dysphonia came from either group A or B and those with moderate dysphonia were from group C. Patients in group D all displayed severe

dysphonia. *Conclusions:* Voice outcome can be accurately predicted by preoperative endoscopic imaging and dynamic assessment of the extent of glottic involvement. Poor vocal quality outcome post PCTR is highly likely if the patient had associated glottic involvement. *Relevance to current study:* This study's emphasis on postPCTR vocal outcomes in children could possibly relate to similar results in vocal outcomes post CTR in adults. It serves as a good foundational study for comparison of results.

Grillo, H. C., (1982). Primary reconstruction of airway after resection of subglottic laryngeal and upper tracheal stenosis. *The Annals of Thoracic Surgery*, 33, 3-18. doi:10.1016/S0003-4975(10)63191-8

Purpose: The purpose of this study was to describe the surgical procedures and outcomes of 18 patients with low subglottic laryngeal stenosis and upper tracheal stenosis. *Method:* Ten female and 8 male patients ranging from the ages of 14 to 76 who had all experienced respiratory failure due to some subglottic laryngeal inflammatory processes were provided surgical management via reconstruction by primary laryngotracheal anastomosis and resection of the anterior and lateral cricoid cartilage and upper trachea. Only 1 of the 18 had no prior treatments and only 2 were diagnosed with idiopathic subglottic stenosis (SGS). The other patients had one or more prior minor treatments and eight had undergone major surgical procedures including reconstruction to address a secondary SGS. *Results:* Surgical outcomes in 15 patients had good to excellent results as far out as five and one-half years postsurgery. One patient is considered to have had satisfactory results on the basis of experiencing shortness of breath during heavy exertion. One patient's reconstruction failed due to the nature of their etiology being a burned airway. The other patient is still under treatment with the aid of a T-tube. *Conclusions:* The one-stage reconstructive surgical technique is a valid and advantageous approach to resolving severe stenosis in patients. *Relevance to current study:* This study demonstrated the advantages of resection for patients suffering from severe stenosis. The current success being experienced with this surgery will likely lead to it being used more frequently. This supports the current study's aim of investigating the effect of stenosis and resection on vocal quality.

Grillo, H. C., Mathisen, D. J., Wright, C. D., Ashiku, S. K., Wain, J. C. (2003). Successful treatment of idiopathic subglottic stenosis by resection and primary anastomosis. *Annals of Otolaryngology, Rhinology, and Laryngology*, 112, 798-800. doi: 10.1177/000348940311200909

Purpose: This study examined idiopathic laryngotracheal stenosis (ILTS) in a group of 73 patients. It reported on both the early and long-term response of ILTS to treatment via single stage laryngotracheal resection and reconstruction. *Methods:* Data were collected through detailed questionnaires and chart review. Seventy-one of the 74 patients were female. Ages ranged from 13-74 years. *Results:* Overall good to excellent results were achieved in 90% of the patients as reported from an eight year follow-up. Twenty-six percent of patients reported no difficulties in breathing at rest or in exercise and no change in their voice. However, 64% of patients noted difficulty in singing and projecting their voice and 7% demonstrated dyspnea on moderate exertion, the need for occasional dilation, and noisy breathing. *Conclusions:* The data from this study indicate ILTS to be effectively treated initially and in the long-term by careful single stage laryngotracheal resection and reconstruction. *Relevance to current study:* This study

was similar to the current study in that the target population was mostly adult females. Although ILTS was primarily examined, it is closely related to idiopathic subglottic stenosis, which is the focus of the current study. The vocal quality of the patients in this study will provide a relevant comparison for the current study.

Hartley, B. E. J., Rutter, M. J., & Cotton, R. T. (2000). Cricotracheal resection as a primary procedure for laryngotracheal stenosis in children. *International Journal of Pediatric Otorhinolaryngology*, 54, 133-136.

Purpose: This study focused on the outcomes achieved by performing a primary cricotracheal resection (CTR) on children with severe laryngotracheal stenosis. *Methods:* The department of pediatric otolaryngology in the Children's Hospital Medical Center in Cincinnati Ohio kept a prospective database since 1974 containing more than 1000 LTR procedures and over 50 CTRs. Patients requiring a CTR as a primary treatment were identified and any necessary supplementary information was provided to the database from the patient's medical records. Decannulation rate was the primary outcome the authors looked for. Data from seventeen children were included. *Results:* Seventeen children with Cotton grade 3 or 4 stenosis all underwent a primary CTR with no prior upper airway surgical procedures between the years 1994 to 1998. Following a minimum one year follow up, fifteen of the seventeen had achieved decannulation, although five required further surgery to achieve decannulation, and two are still tracheostomy dependent. Post CTR the children's vocal quality was assessed subjectively as good, acceptable, weak, or absent. Nine children's voices were deemed good, five were acceptable, two were weak, and one had no voice due to complete re-stenosis of the subglottis. *Conclusions:* All surgical procedures should be carefully evaluated on an individual basis to meet the specific needs of the patient. However, CTR is indicated as an appropriate and successful surgical technique for re-establishing a viable airway for children with severe Cotton grade 3 or grade 4 LTS with or without other prior surgical attempts. *Relevance to current study:* In this study a good voice was achieved post CTR in the majority of patients and those who achieved less than good had additional complications that may or may not factored into the vocal quality. The study calls for more research in the area of postsurgery vocal quality across multiple airway surgical techniques to further inform surgeons when they must determine the best surgical approach for their patients as well as for the patients when deciding what surgical approach would be best for them. The current study is examining the vocal quality of SGS patients post CTR.

Houlton, J. J., de Alarcon, A., Johnson, K., Meinzen-Derr, J., Baker-Brehm, S., Weinrich B., & Elluru, R. G. (2011). Voice outcomes following adult cricotracheal resection. *The Laryngoscope*, 121, 1910-1914. doi: 10.1002/lary.21915

Purpose: This study examined the effect of CTR on the voices of adult patients with SGS. *Method:* Medical records from a tertiary referral center of patients with SGS who had undergone a CTR and formal voice evaluations between the years of 2000 to 2010 were reviewed. Extracted information included demographic data, operative reports, acoustic measures, and CAPE-V. Acoustic measures consisted of maximum phonation time, F₀ from a sustained /a/ and connected speech, mean intensity, pitch glides from highest to lowest frequency, jitter, shimmer, and noise to harmonic ratio. Fifteen females and one male patient

with a median age of 44.1 years fit their inclusion criteria and were included in the study. *Results:* Of all the measurements, only mean F_0 for sustained vowel and connected speech showed statistical significance following CTR. The CAPE-V visual analogue scale results indicated that the majority of patients fell within the moderately dysphonic range postsurgery and presurgical evaluations were also abnormal for 40% of patients who scored greater than 33 of 100. *Conclusions:* CTR has a significant negative effect on the adult voice by way of lowering the mean F_0 in vowel phonation and in connected speech. The results in Houlton et al. (2011) study agreed with the findings of Smith et al. (2008) in regards to mean F_0 in sustained vowels and connected speech but not in regards to pitch range reduction. *Relevance to current work:* The current study will also be a retrospective review that will implement many of the same measurements on the adult female voice presurgery and postsurgery.

Hu, A., McCaffrey, J., & Hillel, A. (1997). Cricotracheal resection. *Ear, Nose, and Throat Journal*, 96, 391-402.

Review Article: This article was a review of a single case of laryngotracheal stenosis in an adult female. After undergoing 27 endoscopic dilations it was decided to administer a cricotracheal resection to her. After surgery endoscopic evaluation determined her vocal folds were mobile and the repair was smooth and open. However, four months postsurgery the patient experienced a recurrence of her subglottic stenosis, for which she underwent another endoscopic dilation and was administered an injection of triamcinolone. This proved to be effective and nine months postsurgery the patient was still stenosis free and happy with her results. Although this article made no mention of the patient's satisfaction with her vocal quality postsurgery it still provided useful information regarding cricotracheal resection and its recovery process.

Hseu, A. F., Benninger, M. S., Haffey, T. M., & Lorenz, R. (2014). Subglottic stenosis: A ten-year review of treatment outcomes. *The Laryngoscope*, 124, 736-741.
doi: 10.1002/lary.24410

Purpose: This study examined treatment outcomes of adult patients with SGS who underwent endoscopic surgical management over a 10-year period. *Method:* This was a retrospective chart review of 92 adult patients (69 female, 23 male) diagnosed with SGS from the years 2001 to 2010. Extracted case history information included age, gender, presenting symptoms, and comorbidities such as history of cardiac pulmonary and gastroesophageal reflux disease. Etiology of stenosis, stenosis grade, and surgical dates for each patient were also examined. Measurements used included the Voice Handicap Index and maximum phonation time. Statistical analysis of the data was reported in standard deviation, t-tests, Kaplan-Meier estimation, and Cox regression for odds ratio estimation. *Results:* All patients reported at least one comorbid condition. Of the 92 participants, 45% of them had their SGS attributed to a previous diagnosis of granulomatosis with polyangiitis, 33% were idiopathic, and 25% had a history of prolonged intubation. Among the 92 patients there were a total of 247 surgical procedures. More than half of patients required multiple surgeries. All patients reported experiencing improvement of symptoms postsurgery. Factors leading to subsequent surgical management were, time postsurgery, SGS severity, and the use of sickle knife or scissors versus laser surgery. Injections of steroids at time of first surgery did not increase the time between additional surgeries. All but one of the patients received voice assessments presurgery and

postsurgery. The voice assessments included videostroboscopy, Voice Handicap Index, and maximum phonation time. These indicated that a majority (83) of patients presented with mild to no voice complaints, however, there were some (eight) who were considered dysphonic. Forty-four patients received both presurgical and postsurgical voice assessments and their results indicated improvement in both Voice Handicap Score and maximum phonation time.

Conclusions: When SGS was managed endoscopically, patients experienced improved symptomology (breathing symptoms improved but the rates of recurrence remained elevated). The application of mitomycin C, injection of steroids, method of scar lysis, or etiology all made no difference on the need for multiple procedures or the time between procedures. *Relevance to the current work:* The subset of patients who completed the Voice Handicap Index both presurgery and postsurgery demonstrated an improvement in voice quality, which is different than all the previous works and could be indicative of a novel surgical technique or the mixed population of males and females. This is of interest to the current study, which is also investigating the effect of CTR on the voice.

Monnier, P., Lang, F., Savary, M. (1999). Cricotracheal resection for adult and pediatric subglottic stenosis: similarities and differences. *Operative Techniques in Otolaryngology: Head and Neck surgery, 11*, 311-315. doi: [http://dx.doi.org/10.1016/S1043-1810\(99\)80014-1](http://dx.doi.org/10.1016/S1043-1810(99)80014-1)

Review Article: The aim of this article is to show cricotracheal resection (CTR) as an equivalent if not superior surgical technique in comparison to laryngotracheal resection (LTR). This is accomplished through a thorough explanation of the preoperative and operative techniques required to perform a successful CTR for severe SGS patients. Empirical data from a compilation of other research articles were also used as supporting evidence and to show the positive decannulation rates, airway patency, and vocal quality postCTR. This article indicates that CTR will be the primary surgical intervention used for severe SGS for both adults and children in the near future. With the prominence of this surgical technique on the rise it is important to consider the secondary effects of this operation such as the effect it has on the patient's vocal quality. The current study is examining the effect of CTR on the adult female population to gain a better understanding of its impact on the voice.

Monnier, P., Lang, F., Savary, M. (1999). Cricotracheal resection for pediatric subglottic stenosis. *International Journal of Pediatric Otolaryngology, 49*, 283-286. doi: [http://dx.doi.org/10.1016/S0165-5876\(99\)00175-5](http://dx.doi.org/10.1016/S0165-5876(99)00175-5)

Purpose: The purpose of this article was to objectively represent the outcomes of using cricotracheal resection (CTR) on a pediatric population afflicted with severe, Cotton grade III or IV, stenosis. *Methods:* Thirty-eight infants and children afflicted with severe, Cotton grade III or IV, subglottic stenosis between the years 1978 and 1998 were administered a partial cricoid resection with primary thyrotracheal anastomosis. The etiology for the majority of patients was prolonged intubation, and was congenital in only seven patients. *Results:* There were no mortalities, and only one complete restenosis; two patients achieved a better than grade 1 stenosis, and a normal lumen was achieved in 35 patients. Thirteen patients were reported as having moderate dysphonia, mostly pertaining to pitch of voice, postoperatively. Twenty-four patients had a normal voice postoperatively. An overall decannulation rate of 95% was achieved.

Conclusions: The results of this study indicate that the CTR is a superior surgical approach to managing severe subglottic stenosis in children as compared to the currently preferred method of laryngotracheoplasty. *Relevance to current study:* This is another study that is indicative of the growing use of CTR to resolve subglottic stenosis. It also provides some reporting of vocal quality postCTR. The data on voice quality in this study are vague and limited but still indicative of the potential high risk of vocal damage. The current study aims to provide more detailed and objective measurements of the CTR's effect on vocal quality so that patients and surgeons alike can make more informed decisions.

Nouraei, S. A. R., Chir, B., & Sandhu, G.S. (2013). Outcome of a modality approach to the management of idiopathic subglottic stenosis. *The Laryngoscope*, 123, 2474-2484. doi:10.1002/lary.23949

Purpose: This study set out to determine the effectiveness of a multimodality approach used to treat idiopathic subglottic stenosis (ISGS), identify predicting factors of treatment success, and improve definitions of the limitations and roles of endoscopic and open surgery. *Method:* Fifty-four patients presenting with idiopathic subglottic stenosis were treated with either endoscopic or open surgical procedures between the years 2004-2012. Patients were all female and had a mean age of 47.8 +/- 12.1 years at diagnosis. Twenty-one (39%) patients received prereferral treatments prior to being in this study. *Results:* Minimal invasive surgery was required for managing 78% of endoscopically treated patients. The five-year actuarial success rate for endoscopic treatment was found to be higher for patients with subglottic only disease (87.5%) than it was for concomitant glottic and subglottic disease (18.7%). According to the airway-dyspnea-voice-swallowing (ADVS) system, all patients, except, one, who received a laryngectomy were able to maintain prosthesis-and stoma-free airways (A₁) by the final follow-up. Twenty-six patients had D₁ and D₂ dyspnea grades, 41 patients received a V₁ voice, 9 had V₂ voices, four had V₃ or V₄ voices, and 51 patients had a normal swallow (S₁). Male pattern voices were not observed during the study but the suboptimal vocal outcomes were attributed to weak breathy dysphonia. The only significant factor associated with dyspnea and voice outcomes on a multivariable regression analysis was whether or not the disease involved the glottis. *Conclusions:* ISGS is a treatable, insidious, progressive fibromatosis disease primarily affecting women of European ancestry in their fourth or fifth decades of life. The less severe the stenosis the fewer endoscopic interventions are required. For those patients who cannot benefit from endoscopic treatment, the use of airway framework expansion and implantation of biological inhibitors of fibrosis, as described in the article, can achieve long-term disease remission without causing vocal gender reassignment. The only identified factor that was independently associated with dyspnea and suboptimal voice outcomes was glottis involvement at time of presentation. *Relevance to current study:* This study quantified voice outcomes of patients with ISGS after endoscopic and open surgical treatments. A re-examination of the use of cricotracheal reconstructive surgery was also recommended based on the results found in this study. The current study is also examining vocal outcomes post ISGS treatment.

Nakache, G., Primov-Fever, A., Alon, E. E., & Wolf, M. (2015). Predicting outcome in tracheal and cricotracheal segmental resection. *European Archives of Otorhinolaryngology*, 272, 1471-1475. doi: 10.1007/s00405-015-3575-z

Purpose: This study examined multiple factors related to tracheal and cricotracheal segmental resections (TR/CTR) including prognostic factors of successful TR and CTR, revision outcomes, and the type of revisions done in cases of failure. *Method:* Data for the study were obtained through retrospective chart review of patients with SGS who underwent a TR/CTR at a tertiary referral medical center over a 16 year span of time. Successful surgical intervention was considered to be decannulation for patients with tracheotomies or ease of breathing for those without, and phonation for a small subset afflicted with complete airway obstruction as well as cardiopulmonary or neurological conditions that prohibited safe decannulation. *Results:* One hundred twenty-two patients remained eligible through follow up to participate in the study. Eighty-seven patients were male. The successful completion of the primary goal with no need for continued intervention was achieved in 85 patients (68%). However, 36 patients required one or more revision surgeries with a success rate of 69%. Complete obstruction accompanied by aphonia was found in 46 patients (38%). *Conclusions:* TR and CTR were found to be successful in a specific group of patients including those with tracheal stenosis who had non-tracheotomized, cricoid sparing incomplete tracheal stenosis without secondary airway pathologies. Revision surgeries were also found capable of managing stenosis reduction after initial failures of TR/CTR. *Relevance to current study:* There are multiple medical interventions available to patients with tracheal and/or subglottic stenosis. Understanding that both TR and CTR are equally effective helps the patient make more informed decisions about their health care especially when coupled with the current study's findings regarding vocal quality outcomes that accompany CTR.

Parrish, K. L., & Miller, R. H. (1991). Subglottic stenosis. *The Journal of the Louisiana State Medical Society*, 143, 7-10.

Review Article. This review article provided an evidence-based overview of SGS including its history, clinical presentation, anatomy, etiology, and treatment. Notable symptoms mentioned were stridor, dyspnea, a barking cough, hoarseness, and aphonia. Common etiologies discussed included anatomical abnormalities of the larynx and trachea, and previous prolonged intubation. Treatments discussed varied from the least invasive endoscopic procedure to the most invasive laryngotracheal reconstruction. There were benefits and drawbacks to each treatment with the most notable drawback being permanent voice disorders following grafting procedures. This article provided a good overview of SGS as a whole and provided supporting evidence for the negative, albeit unintended, side effects of SGS and the often required surgical management to alleviate the patient from it.

Pearson, F. G., Cooper, J. D., Nelems J. M., Van Nostrand, A. W. P. (1975). Primary tracheal anastomosis after resection of the cricoid cartilage with preservation of recurrent laryngeal nerves. *The Journal of Thoracic and Cardiovascular Surgery*, 70, 806-816.

Purpose: This article was a detailed report of six patients who underwent a primary tracheal anastomosis after resection of their cricoid cartilage. *Method:* The surgery included a resection of segments of the trachea and excision of the cricoid arch leaving only a thin posterior shell of cricoid plate all while preserving the recurrent laryngeal nerves. *Results:* In five of the six patients excellent functional results were obtained. Excellent results refer to obtaining improved airway passages. The one patient without excellent results had significant stenosis at the thyrotracheal anastomosis five weeks postoperation. This was thought to be due to the severe damage in the larynx caused by inhalation burns. Some patients had such severely damaged laryngeal nerves prior to the surgery that it was impossible to preserve them. In those patients whose recurrent laryngeal nerves were preserved return to a normal voice was reported within a week to 10 days of operations as soon as the tracheostomy tube was removed, which was no longer than two weeks. *Conclusions:* When the stenosis reaches the level of the subglottis, resection of the cricoid cartilage and tracheal anastomosis has proven to be effective for reopening the airway in a one-step surgery. When the surgery is done with care to preserve the recurrent laryngeal nerves, the voice can also be preserved. *Relevance to current study:* This study is of interest to the current study because it provides a thorough explanation of the cricoid resection and the effect on the voice if the recurrent laryngeal nerves were preserved.

Peterson, E. A., Roy, N., Awan, S. N., Merrill, R. M., Banks, R., & Tanner, K. (2013). Toward validation of the cepstral spectral index of dysphonia (CSID) as an objective treatment outcomes measure. *Journal of Voice*, 27(4), 401-410. doi: 10.1016/j.jvoice.2013.04.002

Purpose of the Study: The aim of this study was to evaluate the validity of the Cepstral Spectral Index of Dysphonia (CSID) as a potential objective measurement of voice treatment outcomes, as well as to determine whether dysphonia severity influenced the accuracy of the CSID. This was done to provide a more standardized approach to assessment and a more objective way to measure voice disorders. *Method:* A retrospective analysis of 112 pre and posttreatment patient audio recordings of sustained vowels and the Rainbow passage was undertaken. All selected patients came from one of six categories; (1) unilateral vocal fold paralysis, (2) adductor spasmodic dysphonia, (3) primary muscle tension dysphonia, (4) benign vocal fold lesions, (5) presbylaryngis, and (6) mutational falsetto. Voice samples ranged along a continuum of mild, moderate, and severe dysphonia. Treatment technique was not considered, so long as a change took place. A comparison of listener ratings and CSID estimates of dysphonia severity was made. *Results:* Listener ratings and CSID estimates were found to be strongly related for both sustained vowels and connected speech in pretreatment, post treatment, and change from pre to posttreatment samples. Severity of the voice sample was not found to impact the relationship between CSID-estimated and listener perceived severity. This was accomplished through a regression analysis. *Conclusion:* The results indicate that across the full range of severities and multiple diagnoses, a strong relationship exists between listener-perceived and CSID estimated dysphonia severities in both sustained vowels and connected speech. This supports CSID as an objective measurement of treatment outcomes in clinical practice. *Relevance to the Current Work:* The CSID acoustic measures accurately mirror listeners'

perceived dysphonia severity ratings. This makes it a useful tool in objective assessment of treatment effects, specifically in the present study following cricotracheal resection in patients with subglottic stenosis.

Pookamala, S., Thakar, A., Puri, K., Singh, P., Kumar, R., & Sharma, S. C. (2014). Acquired subglottic stenosis: aetiological profile and treatment results. *The Journal of Laryngology and Otology*, 128, 641-648. doi: 10.1017/S0022215114000966

Purpose: This was a report compiled from the experiences of multiple surgeons in a single institution regarding the surgical treatment of subglottic stenosis (SGS). The authors compared the diverse SGS treatments and results for patients with SGS. *Methods:* Thirty patients were treated for acquired SGS between the years of 2004 to 2009 in a tertiary care academic institution. Seventeen of the thirty patients' information was retrieved retrospectively; the other 13 patients' were data were acquired prospectively. Surgical interventions used were either endoscopic or external in nature, including cricotracheal resection, depending on the patient's profile. *Results:* Subjects for this research belong to one of two etiological groups: endotracheal intubation injury or external neck injury. Specific acquired subglottic stenosis was found in only 3 out of 30 patients. However, stenosis of the subglottis as well as the trachea was found to be the most common etiology. Surgical intervention was dependent on multiple factors, such as site of involvement, the time since injury, the grade and length of stenosis, and the type of stenosis such as mucosal edema only or cartilaginous framework involvement as well. After surgery, 29 of 30 patients had their lumen restored. However, luminal restoration was achieved with a single procedure in 11 patients and multiple procedures were required for the other 19 patients. External procedures proved to be major contributors to surgical success in 27 of the 30 patients. When endotracheal procedures were used primarily they were only found to be successful in 2 out of the 8 patients. *Conclusions:* Stenosis caused by intubation injury has a better profile than stenosis caused by external injury. Surgical procedure selection can be successfully guided by specific anatomical categorization of stenosis. Endoscopic procedures are useful as adjunctive procedures more so than primary procedures. *Relevance to current study:* This study clearly indicated that subglottic stenosis is rarely confined to just the subglottis, but more commonly includes the trachea and glottis. Knowing this can bring greater understanding to the common voice changes that accompany subglottic stenosis prior to any surgical management.

Primov-Fever, A., Talmi, Y. P., Yellin, A., & Wolf, M. (2006). Cricotracheal resection for airway reconstruction: The Sheba Medical Center experience. *Israel Medical Association Journal*, 8, 543-547.

Purpose: The purpose of this study was to review 10 years of patient records to summarize complications and pitfalls associated with cricotracheal resection (CTR). *Method:* The medical records of 61 patients who had undergone CTR in the Sheba Medical Center between the years of 1995 and 2005 were retrospectively reviewed. Age, gender, medical histories, preoperative evaluations, grade of stenosis, glottis functioning, and presence of a tracheotomy were described for each patient. *Results:* Fifty-seven of the original 61 patients were successfully decannulated, most of whom were completed in a single stage. Re-stenosis occurred in 9% of patients; however, four of the six patients were eventually decannulated within three to six months. During the 30-day postoperative time there was a 1.6% mortality rate (1 patient).

Near normal airway patency was achieved in 55 of the patients. *Conclusions:* Anastomosis tension proved to be the most detrimental factor affecting the success rate of the CTR. Despite the nearly exclusively female population of patients requiring CTR, gender was not established as a significant factor. CTR, both primary and staged, resulted in a high success rate and low morbidity. *Relevance to current study:* CTR is only one of many medical interventions for subglottic stenosis. The information gathered in this study supports the effectiveness of using the CTR in stenotic patients as well useful descriptions of the CTR procedure. The detailed description of the procedure provides understanding of the anatomical changes that generally occur in the patient during CTR.

Smith, M. E., Roy, N., Stoddard, K., & Barton, M. How does cricotracheal resection affect the female voice? (2008). *Annals of Otolaryngology, Rhinology, & Laryngology*, 117, 85-89.

Purpose: The purpose of this study was to quantify the effects of CTR on the adult female voice. *Method:* Researchers examined the medical records of 14 women, mean age 53 years, with idiopathic SGS who had undergone CTR at their facility within the last five years. They compared patient performance via voice recordings taken presurgery and postsurgery. Measurements used in the recording included maximum phonation time, F_0 of sustained vowel /a/ “at a comfortable pitch and loudness,” mean F_0 of speaking voice during reading of the Rainbow Passage, and F_0 glides from midrange to the highest and lowest obtainable pitches on the vowel /a/. *Results:* The mean F_0 of a sustained vowel /a/, connected speech F_0 , and F_0 glides at a comfortable pitch and loudness were the most sensitive, showing a significant difference postsurgery in all the patients. *Conclusions:* CTR in women has the potential for significant lowering of F_0 , lowering of F_0 range, and decreasing the highest attainable pitch. *Relevance to current work:* The current study will be studying a similar population and using like measurements for the common purpose of determining the effect of CTR on the adult female voice. This study serves as a good reference for the creation of the current study and will serve as a good comparison afterwards.

Smith, S. L. (2011) *Influence of subglottic geometry on computational and synthetic vocal fold model vibration* (Master’s thesis). Brigham Young University, Provo, Utah.

Purpose: The goal of this thesis was to determine the role subglottic geometry plays in vocal fold vibration in synthetic and computational vocal fold models. *Methods:* Research was accomplished through three separate yet related studies. First, a two-dimensional self-oscillating finite element vocal fold model was used to determine the effect the inferior vocal fold surface angle had on voice production. Second, in a similar computational model as the used in the first study, SGS was introduced and parametrically varied to evaluate the influence SGS has on vocal fold vibration. Third, a synthetic model was used to determine the effects of SGS on the vibration of the vocal folds. For both the computational model as well as the synthetic model, the following levels of stenosis severity and pressures were used: 0%, 60%, and 95% stenosis and P_{0n} , $P_{1.25}$, and $P_{1.5}$ pressures. *Results:* In the first study significant changes in vibratory motion, flow rate, energy transfer, and glottal width were found through varying the inferior angle. This change was mainly attributable to changes structurally rather than aerodynamically. The second study revealed that only the highest level of SGS severity (95%) had a significant impact on vocal fold vibration, glottal width, flow resistance, flow rate, and vibration sequence. The results

of the third study were consistent with the computational study in that changes were seen at high severity levels. Three areas that showed the most change were radiated acoustic sound, which by consequence lead to change in glottal efficiency as well as subglottal pressure. *Conclusions:* Vocal Fold vibration was found to be significantly altered when the inferior angle of the model was varied in the first experiment using the fully-flexible model simulations. The computational model results indicate that significant decreases in maximum flow declination rate and frequency in the presence of more severe stenosis could cause changes in the power and sound of the voice. The synthetic testing results indicated significant pressure drops, which may impact the human voice. Both the computational and synthetic models showed that vocal fold model vibration was affected by subglottic stenosis at the higher level, 90% and above. *Relevance to current study:* This study recommended that future work in this area include in-depth voice quality studies in SGS patients. The current study is attempting to add empirical data regarding the effect SGS has on the voice. The conclusions from this study support the current study's hypothesis that SGS can impact the human voice.

Taylor, S. C., Clayburgh, D. R., Rosenbaum, J. T., & Schindler, J. S. Clinical manifestations and treatment of idiopathic and Wegner Granulomatosis-associated subglottic stenosis. *Journal of the American Medical Association for Otolaryngology—Head & Neck Surgery*, 139, 76-81. doi: 10.1001/jamaoto.2013.1135

Purpose of the study: This study reported features of idiopathic and granulomatosis-related SGS, as well as the results of surgical management in both groups. *Method:* Participants included 24 individuals with idiopathic SGS and 15 with granulomatosis-related SGS. For the idiopathic group, participants were exclusively female with a median age was 45.2 years; for the granulomatosis group, median age was 36.3 years and included equivalent numbers of males and females. Individuals were also classified using the Myer-Cotton staging system for stenosis severity, the presence of gastroesophageal reflux disease, presence of tracheostomy, and the need for endoscopic tracheal dilation procedures. *Results:* Individuals in the granulomatosis-related SGS were significantly younger than those in the idiopathic group; four individuals were diagnosed before the age of 20. In general, individuals in the idiopathic group presented with significantly more severe stenosis. After surgical management involving operative section or reconstruction, all individuals in the granulomatosis-related SGS required subsequent airway dilation procedures, while no additional management was required for the idiopathic group. Similarly, none of the patients in the idiopathic group required subsequent tracheotomy procedures. Males with granulomatosis-related SGS required more frequent postsurgical management. *Conclusions:* Idiopathic SGS is almost exclusive to middle aged females, presents with greater stenosis severity as compared with granulomatosis-related SGS, and is most effectively managed with open airway reconstruction. Granulomatosis-related SGS presents in both genders fairly equally, may occur in younger females, and is associated with greater incidence of tracheotomy and repeated open airway reconstruction procedures. *Relevance to current study:* The population and procedures investigated in this study were supportive and informative to the creation of the current study which is similar in many facets.

Valdez, T., Shapshay, A. M. (2002). Idiopathic subglottic stenosis revisited. *Annals of Otolology, Rhinology, & Laryngology*, 111, 690-695. doi: 10.1177/000348940211100806

Purpose: The aim of this study was to quantify the characteristics of idiopathic subglottic stenosis (ISS) in a group of 16 patients. *Method:* The data for this study were collected retrospectively from chart reviews of 16 qualifying patients, 14 females and 2 males. Patients ranged from 13-73 years of age at time of diagnosis and all were diagnosed ISS by means of excluding any other possible etiology. Data included age at presentation, gender, GERD symptoms and treatment, number and type of surgical procedures, previous endotracheal intubation or local trauma, previous airway infections, and other possibly related systemic illnesses. *Results:* Surgical treatment was required for respiratory failure in 14 patients, nine of whom were managed effectively via endoscopic laser techniques. However, five patients' endoscopic laser procedures ended in failure and required laryngotracheal resection and reconstruction. It was reported that lesions thicker than 1cm were present in all patients who experienced failed endoscopic laser procedures. *Conclusions:* The results indicate that thinner non-complicated lesions are best resolved with endoscopic laser surgery. However, laryngotracheal resection and reconstruction is the better approach to resolving thicker more complex lesions. *Relevance to current study:* This study had a similar population to the current study, involving mostly adult females all of whom were afflicted with ISS. It also provided a fundamental understanding of the illness in the current study's target population.

White, D. R., & Rutter, M. J. (2009). Cricotracheal resection and reanastomosis. *Operative Techniques in Otolaryngology*, 20, 236-240. doi:10.1016/j.otot.2009.10.016

Review Article. This review article discussed in depth the different steps of a CTR as well as important contraindications and possible complications that should be taken into consideration prior to CTR. Of particular importance to the current study is the detailed description of CTR. Knowing the anatomical placements of incisions and extent of displacement is important in understanding the effect CTR can have on the voice. Listed among the complications is the possibility of injury to the recurrent laryngeal nerve with vocal cord paralysis, which would have obvious detrimental effects on the voice. Considering the magnitude of this surgery the authors also strongly recommend the patient receive early postsurgical evaluation by a speech-language pathologist to prevent the development of poor vocal habits. Given the nature of the nature of the current study a sound knowledge of CTR and all of its outcomes is imperative.