The Laryngoscope

Interventions and Outcomes in Glottic Versus Multi-level Airway Stenosis: A Multi-institutional Review

Shambavi J. Rao, BS; Grant E. Gochman, MS; Anastasiya Stasyuk, BS; Kychelle L. Del Rosario, BA; Daniel J. Cates, MD; Lyndsay L. Madden, DO; VyVy N. Young, MD

Objective: Airway stenosis—particularly multi-level—presents complex management challenges. This study assessed rates of tracheostomy, decannulation, and the number of surgeries required in patients with posterior glottic stenosis (PGS), multi-level airway stenosis (MLAS), and bilateral vocal fold paralysis (BVFP).

Methods: Airway stenosis patients treated between 2016 and 2021 at three tertiary medical centers were identified. Demographics, etiology of stenosis, medical comorbidities, and patient-reported outcome measures (PROMs) were collected.

Results: 158 patients (84 women, mean age 56.98 ± 15.5 years) were identified (54 PGS, 38 MLAS, and 66 BVFP). 72.3% required tracheostomy, including 72.2%, 86.8%, and 63.6% in these groups, respectively. Decannulation rates were 43.6%, 21.2%, and 32.5% in these groups, respectively. Patients with MLAS had higher rates of tracheostomy than BVFP ($p < 0.05$). However, decannulation rates were not different between groups ($p > 0.05$). MLAS required more surgeries (mean 4.0 ± 3.9) than PGS (2.4 ± 2.2, $p = 0.02$) or BVFP (1.0 ± 1.8, $p < 0.0001$). Mean PROMs scores at the latest follow-up were abnormal: 15.4 ± 12.2 (Dyspnea Index), 19.9 ± 12.2 (Voice Handicap Index-10), and 9.67 ± 11.1 (Eating Assessment Tool-10). Comorbidities present included body mass index >30 (41.4%), diabetes (31.8%), pulmonary disease (50.7%), gastroesophageal reflux disease (39.4%), autoimmune disease (22.9%), and tobacco use history (55.2%).

Conclusions: Airway stenosis is a challenging clinical problem that negatively impacts patients' quality of life and often requires numerous surgeries. PGS more frequently requires tracheostomy compared to BVFP, but patients can often decannulate successfully. Patients with multi-level stenosis have lower decannulation rates and require more surgeries than glottic stenosis alone; these patients may benefit from earlier and/or more aggressive intervention.

Key Words: airway stenosis, decannulation, posterior glottis stenosis, tracheal stenosis, vocal fold paralysis.

Level of Evidence: 4

***Laryngoscope*, 133:528–534, 2023**

INTRODUCTION

Narrowing of the airway such as occurs in subglottic stenosis, tracheal stenosis, and bilateral vocal fold paralysis (BVFP) may lead to acute airway compromise requiring emergent surgical interventions.[1] However, airway stenosis remains a very challenging clinical entity to manage due to the differences in pathogenesis, involvement of different anatomical subsites, and insidious onset.[2] Particularly, it is important for surgeons to recognize the potential differences between unilevel airway stenosis (e.g., posterior glottic stenosis [PGS] and BVFP) and multilevel airway stenosis (MLAS) to help guide surgical interventions.[1,3] MLAS includes restriction of more than one aspect of the airway; in the current study, MLAS refers to the presence of PGS in conjunction with stenosis of another area (e.g., subglottis, trachea, or supraglottis). The primary pathogenesis of PGS and MLAS includes immunologically driven processes, ischemia, diabetes, length of intubation, or idiopathic causes in addition to a multitude of other etiologies.[1,2,4,5] In contrast, BVFP most commonly occurs as a result of surgery, malignancy, trauma, and neurologic or idiopathic conditions.[6]

Despite the fundamental differences between PGS, MLAS, and BVFP, the clinical presentations are similar with patients typically reporting dyspnea, although this may range from mild shortness of breath to respiratory distress and stridor. Duration of symptoms may also vary, from acute onset to chronic deterioration.[1] Otolaryngologists frequently encounter challenges in management due to the complexities of managing airway stenosis, leading to the rise of innovative techniques. Common

From the Wake Forest School of Medicine (S.J.R., K.L.D.R.), Winston-Salem, North Carolina, U.S.A.; Department of Otolaryngology-Head and Neck Surgery (G.E.G., V.N.Y.), University of California-San Francisco Voice and Swallowing Center, San Francisco, California, U.S.A.; University of California-Davis School of Medicine (A.S.), Sacramento, California, U.S.A.; Department of Otolaryngology-Head and Neck Surgery (D.J.C.), University of California-Davis School of Medicine, Sacramento, California, U.S.A.; and the Department of Otolaryngology-Head and Neck Surgery (L.L.M.), Wake Forest School of Medicine, Winston-Salem, North Carolina, U.S.A.

Editor's Note: This Manuscript was accepted for publication on June 16, 2022.

This work was accepted for a podium presentation at the American Broncho-Esophagological Association (ABEA) at the Combined Spring Otolaryngology Meeting (COSM) in Dallas, Texas on April 30, 2022.

This research did not receive grants from funding agencies in the public, commercial, or not-for-profit sectors. Lyndsay L. Madden, DO is a consultant for Lumenis. The remaining authors have no financial disclosures or conflict of interests relevant to this manuscript.

Send correspondence to VyVy N. Young, MD, Department of Otolaryngology-Head and Neck Surgery, University of California-San Francisco School of Medicine, San Francisco, CA.

University of California-San Francisco Voice and Swallowing Center, 2330 Post St. #500, San Francisco, CA 94115. E-mail: vyvy.young@ucsf.edu

DOI: 10.1002/lary.30269

surgical procedures performed to address airway stenosis include laser excision (performed most often with carbon dioxide [CO_2] laser), airway dilation, transverse cordotomy, partial or total arytenoidectomy, and open surgical (e.g., laryngotracheal) resection.[7,8] Cates et al. investigated the effects of a traditional balloon dilator compared with an anatomically appropriate teardrop dilation technique using a 3-D printed larynx model and found that teardrop-shaped dilation applies greater force toward the posterior glottis. This technique therefore could enhance treatment paradigms for early, sub-acute PGS.[8] Additionally, many patients may require a tracheostomy to ensure immediate airway patency as a result of laryngeal obstruction.[9] However, long-term tracheostomies carry the risk of several complications for patients in the longitudinal post-operative period.[10]

Consequently, it is important to recognize and understand the differences in patients that may successfully undergo tracheostomy decannulation.[9] Prior literature has illustrated that patients diagnosed and treated for type I PGS show promise for excellent prognosis post-operatively with decannulation rates near 80%.[11] Also, a recent case series reported patients most likely to be decannulated after receiving a tracheostomy for laryngotracheal stenosis underwent early otolaryngologic evaluation and had minimal firm scar formation in their granulation tissue.[9]

To date, there is limited literature regarding the outcomes of surgical interventions for glottic versus MLAS. The primary objective of this study was to assess the rates of decannulation in a multi-institutional setting between patients with PGS, MLAS, and BVFP. Secondarily, the authors aimed to quantify the surgical interventions performed and to report quality of life measures utilizing patient-reported outcome measures (PROMs) for patients with airway stenosis. These authors hypothesized PGS has a higher rate of recurrent stenosis and thus has an overall lower rate of decannulation and requires more surgeries to achieve decannulation than BVFP. Furthermore, patients with MLAS are hypothesized to have a lower overall rate of decannulation than those with glottic stenosis (i.e., PGS/BVFP) and require more surgeries to achieve decannulation.

METHODS

This study was a multi-institutional retrospective chart review approved by the institutional review boards at Atrium Health-Wake Forest Baptist (AH-WFB), University of California-Davis Medical Center (UCD), and University of California-San Francisco Medical Center (UCSF). Adult patients ≥18 years of age treated for PGS, MLAS, and BVFP at each of these institutions were identified. Patients were identified between January 2016–October 2021 (AHWFB and UCD) and July 2020–October 2021 (UCSF). The patient selection flow chart is illustrated in Figure 1.

The diagnosis of PGS, MLAS, or BVFP was determined by a fellowship-trained laryngologist. PGS was differentiated from BVFP by either (1) laryngeal electromyography (LEMG), (2) arytenoid palpation, or (3) confirmatory operative findings, including visible scar band, fibrosis, arytenoid fixation, or global movement of the posterior larynx with palpation in a lateral direction. Exclusion criteria included age under 18 years, vulnerable populations such as pregnant or incarcerated individuals, patients without a clear explanation of how airway stenosis diagnosis was determined, and patients

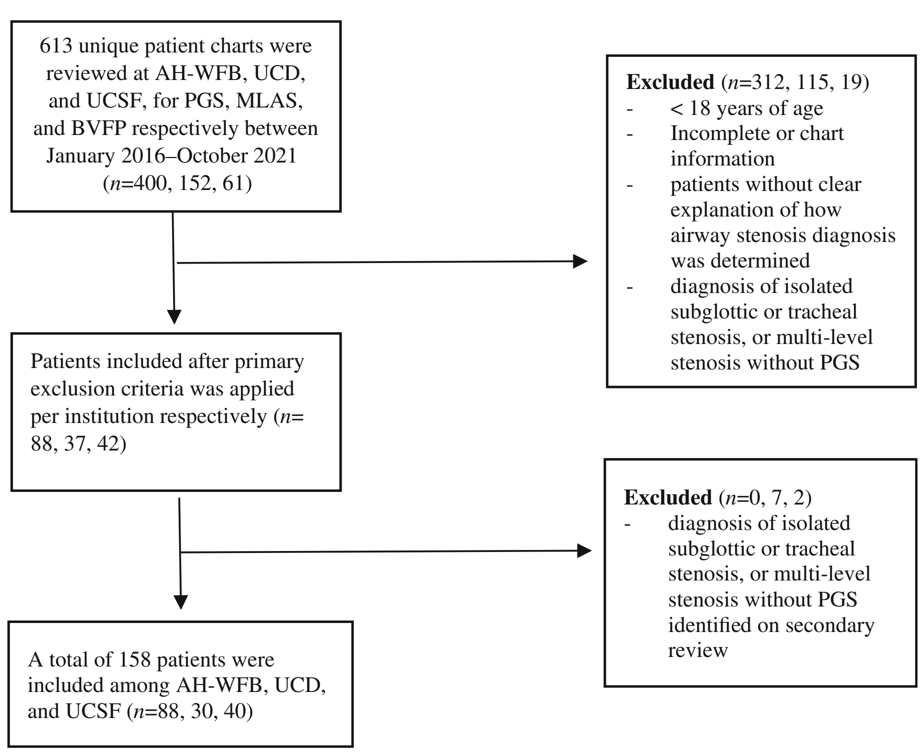

Fig. 1. Consortium diagram of patient selection at Atrium Health-Wake Forest Baptist, University of California- Davis, and University of California- San Francisco.

TABLE I.
Comprehensive Details About Airway Stenosis Patients, Their History, and Their Treatment.

	Overall Cohort	PGS	MLAS	BVFP
Demographics				
Age, mean (SD)	57 (15.5)	59.6 (14.1)	52.9 (13.2)	57 (17.4)
Sex, female, *n* (%)	84 (53%)	23 (27%)	26 (31%)	35 (42%)
Ethnicity				
Caucasian, *n* (%)	91 (58%)	33 (36%)	21 (23%)	37 (41%)
Black, *n* (%)	24 (15%)	8 (33%)	6 (25%)	10 (42%)
Hispanic, *n* (%)	23 (15%)	7 (30%)	6 (29%)	10 (43%)
AAPI, *n* (%)	7 (4%)	2 (29%)	2 (29%)	3 (43%)
Unknown/NOS	7 (4%)	2 (29%)	1 (14%)	4 (57%)
Middle Eastern, *n* (%)	3 (2%)	1 (33%)	1 (33%)	1 (33%)
Other, *n* (%)	2 (1%)	0 (0%)	1 (50%)	1 (50%)
Biracial, *n* (%)	1 (1%)	1 (100%)	0 (0%)	0 (0%)
Comorbidities				
BMI>30, *n* (%)	65 (41%)	25 (38%)	15 (23%)	25 (38%)
Diabetes, *n* (%)	50 (32%)	19 (38%)	15 (30%)	16 (32%)
Pulm disease, *n* (%)	73 (46%)	24 (33%)	20 (27%)	29 (40%)
GERD, *n* (%)	61 (39%)	19 (31%)	23 (38%)	19 (31%)
H&N XRT, *n* (%)	26 (16%)	8 (31%)	6 (23%)	12 (46%)
AI disease, *n* (%)	36 (23%)	9 (25%)	8 (22%)	19 (53%)
Tobacco use, *n* (%)	85 (54%)	35 (41%)	15 (18%)	35 (41%)
Type of stenosis				
Type of stenosis, *n* (%)	158 (100%)	54 (34.2%)	38 (24.1%)	66 (41.2%)
Method of diagnosis				
Physical exam findings, *n* (%)	109 (69%)	37 (34%)	35 (32%)	37 (34%)
LEMG, *n* (%)	8 (5%)	0 (0%)	0 (0%)	8 (100%)
Outside ENT determined, *n* (%)	30 (19%)	12 (40%)	2 (7%)	16 (53%)
Suggestive history without fixation, *n* (%)	11 (7%)	5 (45%)	1 (9%)	5 (45%)

AAPI = Asian American and Pacific Islander; AI = autoimmune dise; BMI = body mass index; BVFP = bilateral vocal fold paralysis; GERD = gastroesophageal reflux disease; H&N XRT = head and neck radiation; LEMG = laryngeal electromyography; MLAS = multi-level airway stenosis; NOS = not otherwise specified; PGS = posterior glottic stenosis; Pulm = pulmonary.

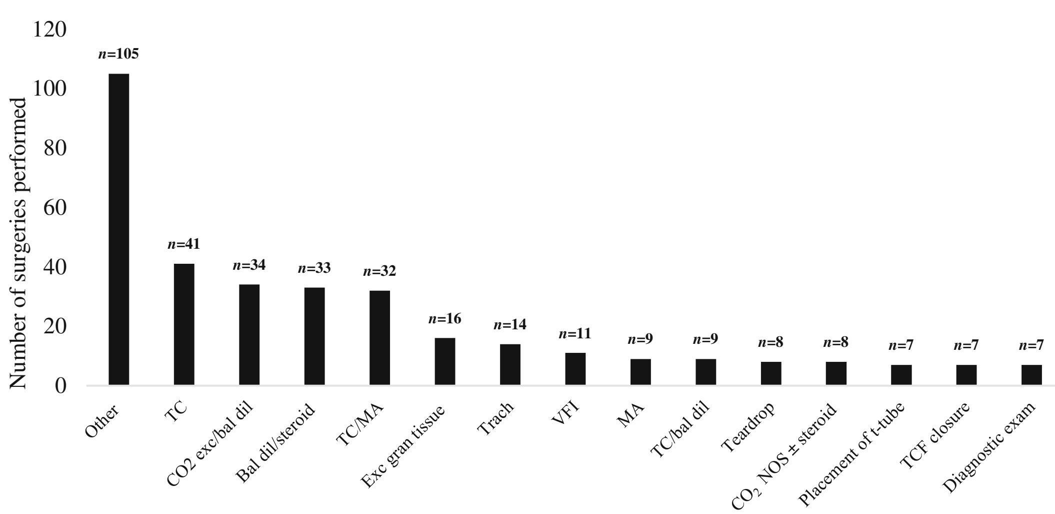

Fig. 2. Most common surgical procedures performed to address airway stenosis. Bal dil/steroid = balloon dilation ± steroid injection; CO_2 exc/bal dil = CO_2 laser excision of stenosis with balloon dilation ± steroid injection; Exc gran tissue = excision of granulation tissue; MA = CO_2 laser medial arytenoidectomy; NOS = not otherwise specified; TC = CO_2 laser transverse cordotomy; TC/bal dil = combined CO_2 laser transverse cordotomy with balloon dilation; TC/MA = CO_2 laser combined transverse cordotomy/medial arytenoidectomy; TCF = tracheocutaneous fistula; Teardrop = teardrop glottic dilation (i.e., rigid dilator with balloon dilation); Trach = tracheostomy; VFI = vocal fold injection (augmentation).

TABLE II.
Surgical Management of Unilevel and Multilevel Stenosis.

	Mean No. of Surgeries (SD)	Mean Time Between Surgeries (Months) (SD)	No. of Patients Requiring Tracheostomy (%)	No. of Patients Achieving Decannulation (%)
PGS	2.35 (2.19)	5.10 (14.5)	39/54 (72.2%)	17/39 (43.6%)
MLAS	4.00 (3.92)	6.1 (7.5)	33/38 (86.8%)	7/33 (21.2%)
BVFP	1.02 (1.80)	9.6 (2.5)	42/66 (63.6%)	13/42 (31.0%)

with a diagnosis of isolated subglottic or tracheal stenosis, or multilevel stenosis without PGS.

Demographics, PROMs (i.e., dyspnea index (DI), eating assessment tool-10 (EAT-10), and voice handicap index-10 (VHI-10)), nature and determination of diagnosis, tracheostomy and decannulation status, and medical and surgical history were collected (Table I). Initial tracheostomy (e.g., at presentation) was not counted toward the total number of surgeries. The most common surgical procedures to address airway stenosis are listed in Figure 2. A list of other surgical procedures performed is provided in the Appendix A. Decannulation rates were determined based on those patients who underwent tracheostomy at any point in treatment, which was then able to be removed by the time of their last follow-up visit.

The statistical analysis was conducted utilizing Microsoft Excel (version 16.49) and GraphPad Prism 9 (version 9.3.1). Descriptive statistics included computation of the mean, standard deviation (SD), and percentage (%). Statistical significance was calculated by student's t-test with Welch's correction for the mean number of surgeries between the groups, mean time between surgeries, and the change of PROMs (e.g., DI, EAT-10, VHI-10) between the three cohorts. Fischer's exact test was used to compare the tracheostomy and decannulation rates.

RESULTS

A total of 158 patients were identified across all 3 institutions, including 54 with PGS, 38 with MLAS, and 66 with BVFP. Women comprised 53% of the patient population. The majority of patients included in this study were Caucasian (58%), followed by Black (15%) and Hispanic (15%). The remaining patients identified as Asian American Pacific Islander (AAPI) (4%), Unknown (4%), Middle Eastern (2%), other (1%), and biracial (1%). Common co-morbidities included body mass index (BMI) >30 (present in 41.4% of all patients), diabetes (31.8%), pulmonary disease (50.7%), gastroesophageal reflux disease (GERD) (39.4%), autoimmune disease (22.9%), previous head and neck cancer radiation (16.8%), and tobacco use history (55.2%). Patients' clinicopathological data and additional information are highlighted in Table I.

The most common surgical procedures performed are illustrated in Figure 2. Patients with MLAS required a greater number of surgeries (mean 4.0 ± 3.9) than those with PGS (2.4 ± 2.2, $p = 0.02$) or BVFP (1.0 ± 1.8, $p < 0.0001$). Also, patients with PGS required significantly more surgeries than patients with BVFP ($p = 0.005$) (Tables II and III). Average time between surgeries was 6.5 ± 14.5 months overall and no difference between groups was found ($p > 0.05$) (Tables II and III).

Overall, a majority (72.3%) of patients required tracheostomy including 72.2%, 86.8%, and 63.6% in PGS, MLAS, and BVFP groups, respectively (Table II). Patients with MLAS had significantly higher rates of tracheostomies than BVFP ($p = 0.0074$). However, PGS had similar tracheostomy rates to both MLAS ($p = 0.1252$) and BVFP ($p = 0.2515$) (Table III).

Decannulation rates were 43.6%, 21.2% and 32.5% in PGS, MLAS, and BVFP, respectively (Table II). Patients with MLAS compared to patients with glottic stenosis (i.e., PGS/BVFP) did not differ in decannulation rates ($p = 0.053$, $p = 0.3064$, respectively). Decannulation rates between patients with PGS and BVFP did not demonstrate statistically significant differences ($p = 0.3588$) (Table III).

PROMs related to breathing, swallowing, and voice (i.e., DI, EAT-10, and VHI-10, respectively) at the initial presentation and most recent office visits are reported in Table IV. These results were available for most patients, with better representation in PGS and MLAS (77%–84%) than BVFP (47%–76%). Mean DI, EAT-10, and VHI-10 were abnormally elevated at both time points for the entire study cohort as well as for each individual subgroup. There was no difference between the change in PROM scores before and after intervention across PGS, MLAS, and BVFP ($p > 0.05$) (Table V).

DISCUSSION

This study evaluated the differences in surgical management as well as tracheostomy and decannulation rates

TABLE III.
Comparison of Surgical Management Between Unilevel and Multilevel Stenosis.

	Mean No. of Surgeries	Mean Time Between Surgeries	Tracheostomy Rate	Decannulation Rate
PGS versus MLAS	0.023**	0.561	0.125	0.053
PGS versus BVFP	0.0005**	0.196	0.252	0.359
MLAS versus BVFP	<0.0001**	0.138	0.007**	0.306

**Denotes significance (p-value <0.05).

TABLE IV.
PROMs at Initial and Most Recent Office Visit for Patients with Airway Stenosis.

	Total Cohort		PGS		MLAS		BVFP	
	N (%)	Mean (SD)	*N* (%)	Mean (SD)	*N* (%)	Mean (SD)	*N* (%)	Mean (SD)
DI initial	119 (75.3%)	20.55 (12.20)	43 (79.6%)	20.90 (12.22)	32 (84.2%)	21.34 (11.50)	44 (66.7%)	19.61 (12.87)
DI final*	108 (68.4%)	15.40 (12.23)	42 (77.8%)	14.14 (13.09)	31 (81.6%)	14.65 (11.14)	35 (53.0%)	17.57 (12.15)
EAT-10 initial	119 (75.3%)	11.62 (11.38)	42 (77.8%)	9.71 (10.85)	30 (78.9%)	10.13 (10.97)	47 (71.2%)	14.28 (11.79)
EAT-10 final	107 (67.7%)	9.67 (11.05)	42 (77.8%)	9.60 (11.56)	31 (81.6%)	8.71 (10.03)	31 (47.0%)	10.65 (11.53)
VHI-10 initial	127 (80.4%)	22.76 (12.36)	45 (83.3%)	22.11 (11.43)	32 (84.2%)	22.81 (13.40)	50 (75.8%)	23.32 (12.69)
VHI-10 final	110 (69.6%)	19.89 (12.12)	43 (79.6%)	20.40 (11.90)	31 (81.6%)	19.29 (12.47)	36 (54.5%)	19.81 (12.30)

*Final = most recent office visit.
DI = dyspnea index; EAT-10 = Eating Assessment Tool-10; PROMs = patient reported outcome measures; VHI-10 = Voice Handicap Index-10.

between patients with PGS, MLAS, and BVFP. The demographics of patients in this study (53% women, mean age 57 years) paralleled the demographics of patients seeking laryngology care at academic medical centers (63% women, mean age 60 years).[12] Additionally, the patients included in this study had several risk factors including diabetes and tobacco use as was previously described by Rosen et al. and Hillel and colleagues in patients with airway stenosis.[2,4] With ongoing efforts to identify trends of modifiable co-morbidities, otolaryngologists continue to play a prominent role in counseling patients and in advocating for preventative measures against laryngotracheal stenosis.

Comparable to other studies,[13] a majority of patients in this study underwent microlaryngeal surgery with CO_2 laser. However, it is notable that CO_2 laser was utilized in various ways, such as for excision of scar band, incision of stenosis, or glottic enlargement surgery (e.g., transverse cordotomy or arytenoidectomy). Patients with MLAS frequently required higher rates of surgical intervention than patients with glottic stenosis (i.e., PGS/BVFP) alone. These results are similar to the findings of Sinacori and colleagues who reported that patients with multilevel tracheal stenosis required an average of 6.7 procedures compared to 2 or 3 procedures in patients with pure glottic or tracheal stenosis, respectively.[13] Maeso-Plaza et al. also demonstrated in their cohort of 34 patients that additional surgical interventions were required in those patients who had PGS combined with another type of laryngotracheal stenosis.[14] MLAS may be associated with poorer outcomes as the etiology of stenosis may be multifactorial and differ in anatomical subsite or rate of progression. Earlier airway surveillance and interventions may improve patient outcomes and decrease the number of surgeries performed on patients with MLAS.

TABLE V.
Comparison of PROMs Between Unilevel and Multilevel Stenosis.

	PROMs		
	Δ DI	Δ EAT-10	Δ VHI-10
PGS versus MLAS	0.752	0.673	0.447
PGS versus BVFP	0.197	0.516	0.414
MLAS versus BVFP	0.120	0.733	0.907

Significance defined as *p*-value <0.05.
DI = dyspnea index; EAT-10 = Eating Assessment Tool-10; PROMs = patient-reported outcome measures; VHI-10 = Voice Handicap Index-10.

Regardless of the etiology of airway stenosis, most patients required a tracheostomy. Furthermore, patients with MLAS had greater tracheostomy rates than patients with BVFP. These findings may be explained by the differences in etiology between MLAS and BVFP and the therapeutic challenges patients and surgeons alike face when managing MLAS. Higher rates of tracheostomies may be indicated after multiple failed procedures, due to recurrent stenosis and cricoarytenoid fixation.[5]

In this study, patients with PGS were noted to have a 43.6% decannulation rate. A prior single institutional case series have described type I subsets of PGS to have decannulation rates near 80%.[11] However, the current study evaluated all categories of PGS, was performed in multiple institutions in different geographic areas and had a larger sample size compared to current literature. Additionally, this study found overall higher decannulation rates among patients with glottic stenosis than multilevel stenosis. Although the difference between these rates did not reach statistical significance, this finding suggests that patients with MLAS may benefit from seeking early laryngeal evaluation and aggressive surgical management to improve long-term post-tracheostomy prognosis.

Airway stenosis may cause acute or chronic upper airway obstruction and significantly impact a patient's quality of life. PROMs are commonly utilized in laryngology to describe the impact of dyspnea, dysphonia, and dysphagia on patients' functionality and quality of life.[15] Patients in the current study reported an improvement in DI, EAT-10, and VHI-10 scores post-operatively across all cohorts; however, none of these changes reached the level of statistical significance. Whether or not these changes represent a *clinically meaningful* difference requires further study. Samad et al. attested to the importance of assessing DI and VHI-10 in endoscopic airway surgery to measure the efficacy of current management and help determine future operative management.[16] Thus, continued PROM administration in the clinic based on commonly reported symptoms associated with airway obstruction may aid surgeons in better understanding the impact of airway enlargement procedures on voice and swallowing function, identifying recurrence, and developing treatment plans.

This study does have notable limitations. First, as a retrospective review, the study was susceptible to observational bias, such as misclassification bias of charts and missing or limited data in patient charts.[17] More detailed descriptions including overall follow-up time period, decision-making about initial tracheostomy (i.e., whether immediately necessary for airway securement versus precautionary measure only), specific classification of PGS subtype, and interval changes in PROM scores after individual interventions were precluded due to the retrospective nature of the present study but will represent an important aspect of future prospective studies. Although the study included three unique institutions, there may still be selection bias or geographic bias related to medical and/or surgical management. Furthermore, the authors analyzed the outcomes at large academic medical centers, so, these results may not be representative across all patient populations and clinical practices such as private practice laryngology clinics. Future directions include analyzing the outcomes of surgical interventions of PGS, MLAS, and BVFP with a greater number of academic and private institutions and among all subsets of PGS.

CONCLUSION

Airway stenosis is a challenging clinical problem that negatively impacts patients' quality of life and often requires numerous surgeries. Patients with multi-level stenosis have lower decannulation rates and require more surgeries than those with glottic stenosis alone. As a result, these patients may benefit from earlier and/or more aggressive intervention. Among those patients with isolated glottic stenosis, PGS can be more difficult to manage than BVFP, and both treatment decision-making and patient counseling merit special consideration.

BIBLIOGRAPHY

1. Gardner G. Posterior glottic stenosis and bilateral vocal fold immobility: diagnosis and treatment. *Otolaryngol Clin North Am*. 2000;33(4):855-878.
2. Rosen C, Wang H, Cates D, Smith L. The glottis is not round: teardrop-shaped glottic dilation for early posterior glottic stenosis. *Laryngoscope*. 2019;129(6):1428-1432.
3. Gadkaree SK, Gelbard A, Best SR, Akst LM, Brodsky M, Hillel AT. Outcomes in bilateral vocal fold immobility: a retrospective cohort analysis. *Otolaryngol Head Neck Surg*. 2018;159(6):1020-1027. https://doi.org/10.1177/0194599818800462.
4. Hillel A, Karatayli-Ozgursoy S, Samad I, et al. Predictors of posterior glottic stenosis: a multi-institutional case-control study. *Ann Otol Rhinol Laryngol*. 2016;125(3):257-263.
5. Guardiani E, Moghaddas HS, Lesser J, et al. Multilevel airway stenosis in patients with granulomatosis with polyangiitis (Wegener's). *Am J Otolaryngol*. 2015;36(3):361-363. https://doi.org/10.1016/j.amjoto.2014.12.010.
6. Hillel A, Benninger M, Blitzer A, et al. Evaluation and management of bilateral vocal cord immobility. *Otolaryngol Head Neck Surg*. 1999;121(6):760-765.
7. Vorasubin N, Vira D, Jamal N, Chhestri D. Airway management and endoscopic treatment of subglottic and tracheal stenosis: the laryngeal mask airway technique. *Ann Otol Rhinol Laryngol*. 2014;123(4):293-298.
8. Cates D, Magnetta M, Smith L, Rosen C. Novel, anatomically appropriate balloon dilation technique of the glottis to treat posterior glottic stenosis in a 3D-printed model. *Laryngoscope*. 2019;129(10):2239-2243.
9. Snow GE, Shaver TB, Teplitzky T, Guardiani E. Predictors of tracheostomy decannulation in adult Laryngotracheal stenosis. *Otolaryngol Head Neck Surg*. 2021;164(6):1265-1271.
10. Halum S, Ting J, Plowman E, et al. A multi-institutional analysis of tracheotomy complications. *Laryngoscope*. 2012;122(1):38-45.
11. Meyer T, Wolf J. Lysis of interarytenoid synechia (Type I Posterior Glottic Stenosis): vocal fold mobility and airway results. *Laryngoscope*. 2011;121(10):2165-2171.
12. Madden L, Hernandez B, Russell G, Wright SC Jr, Kiell E. The demographics of patients presenting for laryngological care at an academic medical center. *Laryngoscope*. Published online 2021.
13. Sinacori J, Taliercio S, Duong E, Benson C. Modalities of treatment for laryngotracheal stenosis: the EVMS experience. *Laryngoscope*. 2013;123(12):3131-3136.
14. Maeso-Plaza A, Dablanca-Blanco M, Ortega-Fernandez C, Ortega-Del Álamo P. Cicatricial posterior glottic stenosis. Our experience. *Acta Otorrinolaringol (Engl Ed)*. 2016;67(6):330-338. https://doi.org/10.1016/j.otoeng.2016.10.002.
15. Rao SJ, Nickel JC, Kiell EP, Madden LL. Readability of commonly used patient-reported outcome measures in laryngology. *Laryngoscope*. Published online 2021. 1-6.
16. Samad I, Akst L, Karataylı-Özgürsoy S, et al. Evaluation of dyspnea outcomes after endoscopic airway surgery for laryngotracheal stenosis. *JAMA Otolaryngol Head Neck Surg*. 2016;142(11):1075-1081.
17. Hess D. Retrospective studies and chart reviews. *Respir Care*. 2004;49(10):1171-1174.

APPENDIX

A.1. OTHER SURGICAL PROCEDURES PERFORMED FOR AIRWAY STENOSIS

Other "CO_2 laser" procedures (e.g., undefined, excision of false vocal fold, etc.)

Awake procedure (e.g., CO_2 laser, balloon dilation, UES dilation).

Undefined "excision of scar" (without clarifying location/modality of excision).

Laryngeal stent (other than t-tube) with or without other procedure(s), including removal.

Combination of tracheostomy with other procedure(s).

Combination of t-tube placement with other procedure(s).

Combination of tracheocutaneous fistula closure with other procedure(s).

Posterior cricoid advancement flap.

Coblator treatment of airway stenosis.

Microflap excision of vocal fold lesion.

Revision of tracheostoma.

Laryngeal reinnervation.

Total laryngectomy.