ORIGINAL ARTICLE

Endoscopic treatment of anterior laryngeal web using keel designed from ePTFE followed by voice therapy: a refined technique

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Abstract

Background: Treatment of laryngeal web is challenging due to possibility of recurrence and affected voice quality. Optimal treatment of laryngeal web should emphasize on improving both airway and vocal function. We refined the traditional endoscopic method using a new keel designed from expanded polytetrafluoroethylene (ePTFE) membrane. Our objective is to evaluate the voice outcomes following the endoscopic treatment and voice therapy.

Results: Ten subjects presented with anterior laryngeal web. Auditory perceptual assessment, stroboscopic examination and acoustic studies were performed pre- and postoperatively. Endoscopic excision of laryngeal web was performed with cold instruments. An individually designed ePTFE keel was fixed by Nylon thread 2–0 at the anterior commissure and tied subcutaneously in the neck. The keel left for 3–5 weeks followed by voice therapy using abdomino-diaphragmatic breathing exercise and relaxation method. Vocal parameters measured were perceptual voice quality using Grade-Roughness-Breathiness-Asthenia-Strain voice scale (GRBAS), stroboscopic score, fundamental frequency (F_0), jitter, shimmer, pitch perturbation question (PPQ), amplitude perturbation question (APQ) and harmonics-to-noise ratio (HNR). Significant decrease in GRBAS ($P < 0.001$) and significant increase in stroboscopic scores ($P < 0.001$) were noticed after operation and voice therapy. Also, acoustic voice parameters showed significant improvements. The mean jitter, shimmer, PPQ and APQ showed significant decrease ($p = 0.0028$, 0.0032, 0.0026, 0.0014, and 0.006 respectively). Overall, 90 % of our subjects have satisfactory voice outcome.

Conclusion: Endoscopic excision of anterior laryngeal with cold instrument followed by ePTFE keel fixation achieved good long-term voice results. The ePTFE is soft biocompatible material which does not make reaction. The keel should be left in place for sufficient period of time (3–5 weeks). This ensures perfect healing with less or no recurrence. Absence of foreign body reactions in the vocal folds is important for mucosal integrity and good voice outcome. So, the ePTFE could be good alternative for laryngeal keel. Hyperfunctional dysphonia with ventricular hypertrophy may develop in longstanding anterior laryngeal web which needs intensive voice therapy after operation. Our treatment targeted both the organic etiology of dysphonia and the underlying cause of the possible associated functional element of dysphonia.

Keywords: Laryngeal web, ePTFE keel, Acoustic analysis, Voice therapy, Vocal functions

Background

Anterior laryngeal web presents mainly by dysphonia and occasionally by breathing difficulty as well [1]. The optimal goals of treatment are to establish patent airway and improve voice quality. Treatment of the laryngeal web is a challenge. The general principle of treatment includes excision of the web and prevention of adhesion

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through placement of a keel [2]. This may be carried out through external approach by laryngofissure [2], internal approach via direct laryngoscopy [3, 4] or both [5, 6]. Different techniques were described to prevent adhesion of vocal folds and recurrence of the web. These included the keel itself which interposed between the two vocal folds [1–6]. Also, covering one vocal fold by silastic sheet with lateralization can prevent recurrence [7]. Moreover, endo-laryngeal web resection through mucosal flap decreases re-adhesion [8]. Application of local mitomycin-c on the raw surfaces of the vocal folds was reported to decrease recurrence [3]. In addition, laser anterior commissurotomy was described to minimize recurrence [9]. The techniques for web excision passed from open surgery to endoscopic approaches over time [1–9]. Also, the material used to prevent re-adhesion passed from Teflon [10] to silicone. Extensive researcher addressed the use of silicone for laryngeal keel for purposes of treatment and prevention of anterior laryngeal webs [11–14]. Nearly all previous researches concerned the airway to prevent web recurrence, but with little concern to the voice quality. Hence, those researches reported good airway postoperatively; however, no enough data available to confirm improved vocal function. In the current research, we used endoscopic excision of the web by cold instruments and fixing a keel designed from an expanded polytetrafluoroethylene membrane (ePTFE). The ePTFE is strong but soft, chemically inert and biocompatible material widely used in medical fields [15]. These properties are important for integrity of vocal fold mucosa. Voice therapy was performed in all subjects after operation. The aim of our treatment is to emphasize the vocal function as well as the airway. The voice was followed up for sufficient period of time by subjective and objective measurements to evaluate the efficacy of our treatment on the vocal function.

Methods
Subjects and methods
This prospective study included 10 subjects (6 females and 4 males) presented with variable degrees of dysphonia due to anterior glottic web in the period from March 2017 to November 2020. Five subjects complained of mild breathing difficulties as well. Inclusion criteria were acquired and congenital anterior laryngeal web with or without subglottic extension of soft tissue. Exclusion criteria were presence of cartilaginous subglottic stenosis and malignant causes. Full history taking and laryngeal endoscopy were performed. Endoscopic examination was performed using fiberoptic nasolaryngoscope model (FNL-10RP3, Hoya Pentax Co., Japan) and rigid laryngoscope (Karl-Storz Endoscope, model 20045020 Germany). The auditory perceptual assessment

of the voice quality was carried out by two experienced Phoniatricians using overall Grade-Roughness-Breathiness-Asthenia-Straining (GRBAS) voice scale [16, 17]. The mean value of GRBAS score was considered. Stroboscopic examination was performed in all subjects. We proposed a simple scoring system for evaluating stroboscopic mucosal wave vibration in the current study by commenting mainly on amplitude/symmetry of vibration. In this scoring system, score 3: normal amplitude of mucosal waves (lateral excursion beyond one-half of upper surfaces of vocal folds) with symmetrical vibration on both vocal folds, score 2: decreased amplitude (lateral excursion less than one-half of upper surfaces of vocal folds) and/or asymmetrical mucosal vibration, score 1: minimal mucosal waves (only vertical component with no lateral excursion) with asymmetrical vibrations, score 0: undetectable mucosal waves. Acoustic analysis was performed by Multi-Dimensional Voice analysis Program (MDVP) model 5105 version 3.3.0 using Kay PENTAX-CSL Model 4500. Using Microphone Shure model SM 48 connected to the CPU, every subject was instructed to phonate the vowel /a/ with comfortable pitch and intensity at a distance of 20 cm from the microphone. The acoustic parameters measured were jitter, shimmer, noise-to-harmonic ratio, pitch perturbation quotient (PPQ), and amplitude perturbation quotient (APQ). The noise-to-harmonic ratio (NHR) obtained by the MDVP was converted into harmonic-to-noise ratio (HNR) in semitones using a specific formula (HNR = $10 \times \log 1/$NHR) [18].

Operative technique
All subjects underwent endoscopic excision of the web with keel fixation. Our operative technique is similar to the traditional endoscopic treatment of the web with some refinements. General endotracheal anesthesia was applied to the patient with a relatively smaller endotracheal tube (6 and 7 mm) for adult female and male respectively. The relatively small tube size is important to avoid trauma and to provide good working space with micro-laryngeal instruments. The web was excised with cold instruments from posterior to anterior. It is important to exert gentle traction on the web during cutting to avoid pulling on healthy mucosa of vocal fold to the trimming line. In subglottic extension of the web, division and excision of the fibrous soft tissue in subglottic area was performed in great caution. Hemostasis was made by compression using cotton pieces soaked in adrenaline solution 1:100,000. During hemostasis, a keel was individually designed from an expanded polytetrafluoroethylene (ePTFE) membrane and a short segment of small suction catheter (size 8). Usually, ePTFE sheet sized 2 × 1.5 cm was cut and folded around the catheter similar to

a butterfly. The wings may be sutured to prevent undesirable folding. The ePTFE keel was individually designed according to the web extent. The average height is 2 cm to be extended from supra- to subglottic areas. In case of subglottic extension of the web, the height of the keel may be longer to ensure covering the subglottic raw area. The catheter was sutured to the middle of the ePTFE sheet by 2–0 nylon thread making two wings (Fig. 1b). Two needles gauge 23 mm were inserted externally in the midline of the neck at 2 levels through thyroid cartilage and cricothyroid membrane. These should be received internally in the supra- and subglottic areas. Cartilage tissue which may be harvested from thyroid cartilage within the upper needle can be removed by stylet, air or 2 cc saline using concomitant suction. The ePTFE Keel was introduced in the direct laryngoscope and the two free ends of thread passed through the needles by crocodile forceps to be received externally (Fig. 1). Then, the Keel was placed vertically in the anterior commissure and both ends of the nylon threads were tied subcutaneously in the midline of the neck (Fig. 1c). The keel was left from 3 to 5 weeks with anti-inflammatory for 1 week and low tapering dose of corticosteroids for 2 months. Weekly visits were mandatory to ensure the keel was in place (Fig. 2B). Tracheostomy is usually not performed unless the keel reached posterior third of the glottis.

Voice rehabilitation

Behavioral readjustment voice therapy started after laryngeal edema had subsided. This usually occurs 8–10 weeks postoperatively and 2 weeks after removal of the keel. The aim of voice therapy is to retrain the vocal folds and the whole vocal tract producing voice without tension or any compensatory faulty behaviors. The main therapy technique used in the current research is abdomino-diaphragmatic breathing exercise (Smith Accent method) [19]. Daily voice therapy session 20 min each, for 2 weeks was performed. In addition, voice training to attain high pitch voice quality was used in selected cases (hypertrophy of ventricular band associated with rough dysphonia). This needed an extra 10 min per session.

Statistics

Comparison between pre- and postoperative evaluations of voice quality, stroboscopic examination, and acoustic analysis were carried out by paired t test with confidence interval 95%. The statistical analysis was conducted by GraphPad Prism 7 software.

Results

Written informed consent for the publication of pictures for laryngeal examinations and personal details including gender, age, and diagnosis were obtained from the participants and from their parent or legal guardian in the case of children under 16. The subjects' personal information, presenting symptoms and details of pathology were shown in Table 1. In this table, the laryngeal web varies from type I through VI according to Cohen's classification [20]. The primary outcome of the preoperative CT revealed subglottic extension of the laryngeal web only in 2 subjects (nos. 7 and 8). This was formed of fibrous soft tissue with no cartilaginous
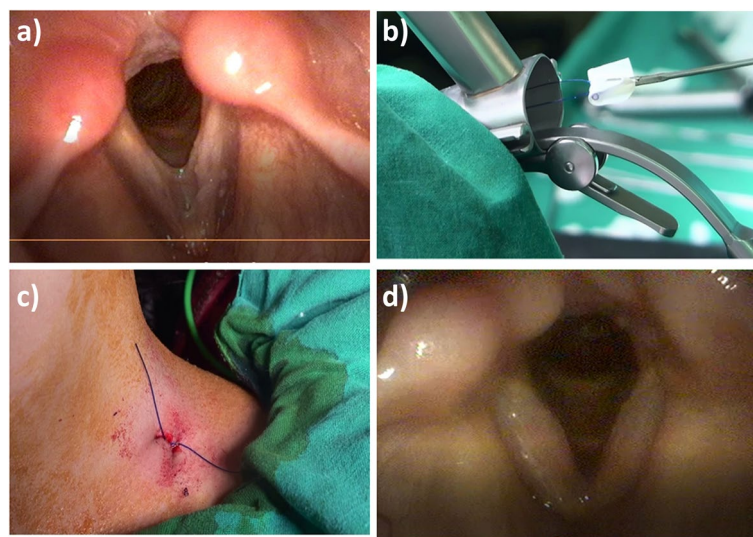

Fig. 1 This figure shows anterior laryngeal web (**a**), ePTFE keel designed and introduced through direct laryngoscope (**b**), the nylon thread tied subcutaneously in the midline of the neck (**c**) and the larynx after 3 months of operation (**d**)
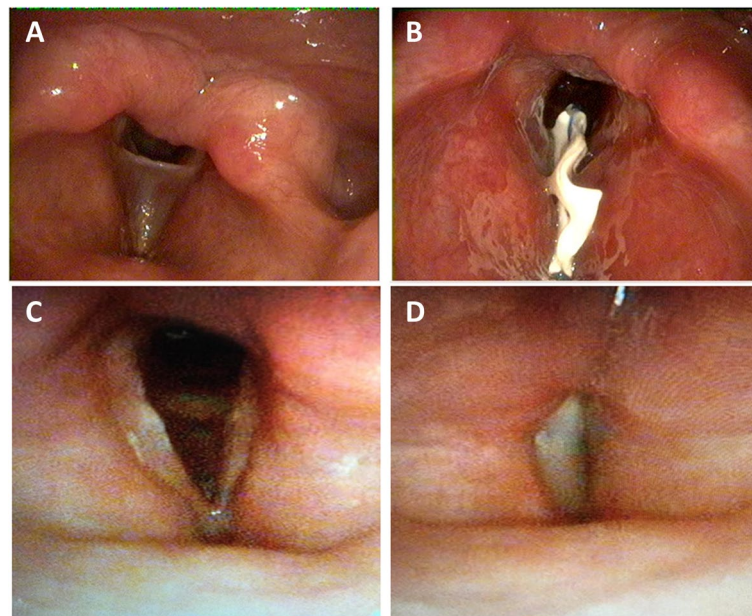
Fig. 2 This figure shows subject with congenital laryngeal web type IV (80%) (**A**). The ePTFE keel was fixed after excision of the web and the subglottic fibrous soft tissue; note the postoperative laryngeal edema (**B**). The larynx after keel removal in inspiration shows some secretions (**C**). Ventricular hypertrophy grade 3 (nearly obscuring the whole left vocal fold) with lateral and anterior-posterior compressions of the larynx during phonation (**D**)

Table 1 Subjects' personal information, symptoms and details of laryngeal web

Subject	Age	Sex	Etiology	Type	Extent	Symptoms
1	16	M	Acquired	IV	85 %	dysphonia, dyspnea on exertion
2	19	M		III	80 %	dysphonia, dyspnea on exertion
3	21	F		III	75 %	dysphonia, dyspnea on exertion
4	24	F		III	60 %	dysphonia
5	18	F		I	30 %	dysphonia
6	19	F		I	25 %	dysphonia
7	20	M	Congenital	IV	80 %	dysphonia, dyspnea on exertion
8	23	M		III	75 %	dysphonia, dyspnea on exertion
9	13	F		II	40 %	dysphonia
10	12	F		I	30 %	dysphonia

Illustrated subjects' information as regard age, gender, clinical presentations, etiology of the laryngeal web and the percentage of glottis involved by the web. Types of the web: type I; the web involves less than 35% of the glottis, type II; from 35-50%, type III; from 50-75%, type IV; from 75-90%, type V; more than 90% of the glottis (Cohen's classification [20]). M: male, F: female

stenosis. Six subjects had acquired anterior laryngeal web. These acquired laryngeal webs were caused by (a) post-inflammatory adhesion following chronic non-specific laryngitis, (b) after repeated or bilateral excisional biopsies from both vocal folds, (c) iatrogenic following endo-laryngeal surgery at anterior commissure followed by anterior webbing or adhesion. Four subjects had congenital anterior laryngeal webs at glottic level.

The first postoperative evaluation for vocal function was carried out after 3 months after surgery to ensure complete subsidence of laryngeal edema. Second postoperative evaluations of vocal functions after 6 months were considered in the comparison. The 10 subjects underwent evaluations at variable time intervals which ranged from 7 to 25 months with average 15.7 months and SD 6.4. The airway was markedly improved after operation in all subjects who were suffering from breathing

difficulties on exertion. The postoperative laryngoscopy carried out over the study period revealed healthy vocal folds with no web recurrence or adhesion in all subjects. Ventricular hypertrophy stage I to II was found in 50% of subjects. Three subjects (nos. 2, 3, and 8) have stage I ventricular hypertrophy; in which, ventricular band covered the anterior third of vocal fold during phonation. In addition, 2 subjects (nos. 1 and 7) have stage II ventricular hypertrophy; in which, ventricular band covered the entire vocal fold during phonation with minimal share in phonation (Fig. 2D). The voice outcomes of our subjects revealed significant improvement as shown below:

GRBAS and stroboscopic mucosal waves (Fig. 3a)

The mean GRBAS (Grade overall) of the perceptual voice quality in all subjects showed significant improvement from 2.2 ± 0.67 to 0.6 ± 0.73 after operation ($P < 0.001$). The auditory perceptual assessment revealed voice improvement in 90% of subjects to nearly normal voice after operation and voice therapy. Initial postoperative evaluation revealed variable grades of functional dysphonia in 5 subjects (50%) which ranged from mild (grade 1) muscle tension (hyperfunctional) dysphonia to (grade 2) ventricular hypertrophy/dysphonia. Three subjects (30%) had mild hyperfunctional dysphonia with/without grade I ventricular hypertrophy. These received behavioral readjustment voice therapy using Smith Accent method with satisfactory voice outcomes. However, two subjects (20%) had ventricular hypertrophy stage II and needed voice therapy by attaining high pitch voice quality as well.

One subject improved in voice quality but the other did not. This subject needed and subjected to surgical excision of the hypertrophied ventricular band. Also, stroboscopic examination revealed mucosal wave vibration in the vocal folds in 90% (9 subjects) which ranged from score 2 to 3. However, there were no stroboscopic waves in one subject with ventricular hypertrophy stage II. The mean score of stroboscopic wave vibration in all subjects was improved significantly from 0.1 ± 0.3 to 2.1 ± 1.2 after operation ($P < 0.001$).

Fundamental frequency (Fig. 3b)

The average fundamental frequency (F_0) was decreased in subjects with congenital laryngeal web from 219.5 ± 7 to 175.5 ± 25 Hz. The mean F_0 for males decreased from 214.5 to 158 Hz; while the mean F_0 for females decreased from 224.5 to 193.5 Hz. In contrast, the F_0 was increased in subjects with acquired laryngeal web from 166.3 ± 38.7 to 190.5 ± 61.5 Hz. The mean F_0 for males increased from 122 to 125 Hz, while the mean F_0 for females increased from 188.5 to 223.25 Hz. Although these changes were consistent with improved voice quality for each sex, the overall changes of the F_0 were insignificant ($P = 0.4$).

Acoustic analysis (Fig. 4)

The mean jitter showed significant decrease in all subjects from 3.5 ± 1.9 to 1.18 ± 0.9 after operation ($P = 0.0028$). Also, the mean shimmer showed significant decrease from 10.25 ± 3.7 to 4.58 ± 1.9 ($P = 0.0032$). In
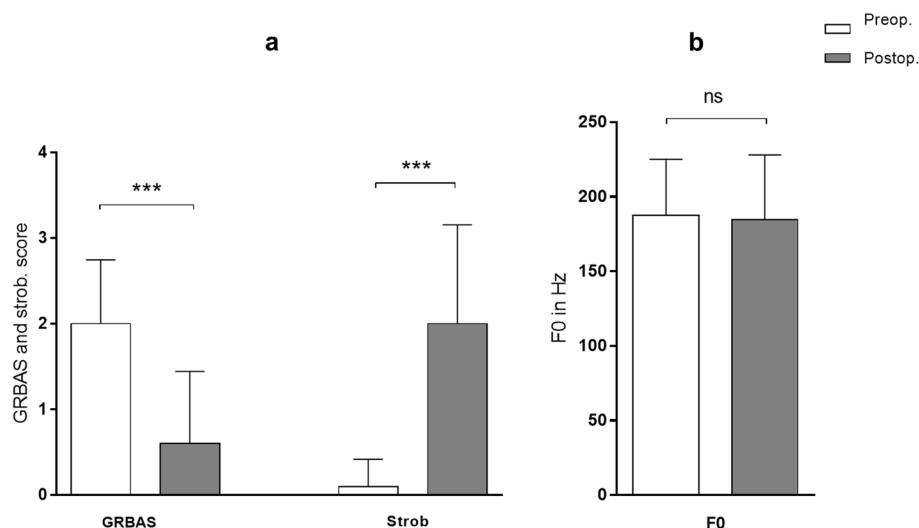

Fig. 3 This figure shows the outcomes of auditory perceptual assessment of the voice quality by GRBAS score and the stroboscopic mucosal waves score. Note the significant improvement in both (decrease grade of dysphonia and increase stroboscopic wave vibrations) (**a**). The fundamental frequency outcome was shown in **b**. GRBAS: Grade overall-Roughness-Breathiness-Asthenia-Strain, strob: stroboscopic mucosal wave, F0: fundamental frequency, Hz: Hertz, preop: preoperative, postop: postoperative, ns: non-significant, ***$P < 0.001$
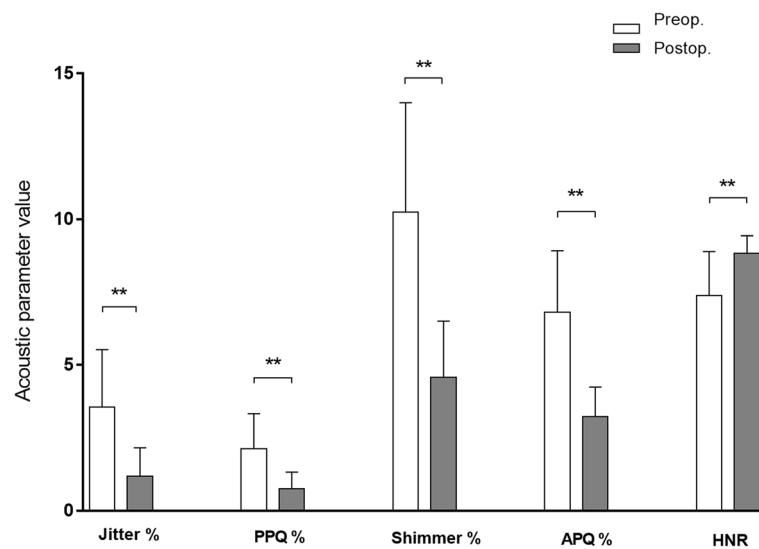
Fig. 4 This figure shows the outcomes of acoustic voice parameters after operation. Note the significant improvement of all voice parameters (increase of HNR and decrease of other parameters). HNR: harmonics-to-noise ratio, PPQ: pitch perturbation quotient, APQ: amplitude perturbation quotient. Preop: preoperative, Postop: postoperative, **$P < 0.01$

addition, the mean PPQ decreased significantly from 2.13 ± 1.2 to 0.75 ± 0.57 ($P = 0.0026$). Moreover, the mean APQ revealed significant decrease from 6.8 ± 2.1 to 3.2 ± 1 ($P = 0.0014$). Finally, the mean HNR revealed significant increase in all subjects from 7.38 ± 1.5 to 8.84 ± 0.6 ($P = 0.006$) postoperatively.

Discussion

Our treatment for anterior laryngeal web in the current research included both endoscopic excision and voice rehabilitation. Endoscopic excision performed by cold instruments followed by fixation of individualized keel designed from ePTFE. Both vocal and respiratory functions were our concern. The ePTFE vascular patch was used for laryngeal keel design. According to comparative study carried out by Ustandag et al. [21] among materials used in medicalization laryngoplasty (ML), silicone, Gore-Tex, and cartilage, the silicone was found to develop fibrous capsule. The fibrous capsule was limited with Gore-Tex (ePTFE). This fibrous capsule may be required in ML implant to prevent extend of reaction to the muscles of vocal fold; so, silicone is good option for ML. For laryngeal keel, the reverse is true because the material is in contact with the vocal fold mucosa. So, the optimal material should produce no or very limited fibrosis to keep healthy vocal folds mucosa. The ePTFE can be considered highly biocompatible material because it does not produce significant allergic, inflammatory, or fibrous reaction in the surrounding tissues. Also, ePTFE is soft and can be designed easily according to the needed size.

Biocompatibility and soft consistency are very important for laryngeal keel to minimize the laryngeal irritation and subsequent cough which might displace the keel or adversely affect the mucosal integrity. In addition, the stiff plastic catheter supported the ePTFE sheet in the anterior commissure. Nylon thread was passed through ordinary syringe needles gauge 23 mm from internal to external. Our treatment had the following advantages: (a) easily practiced and does not need special equipment, (b) does not need laryngofissure or tracheostomy, (c) no collateral heating damage to the vocal folds, (d) suitable for congenital and acquired laryngeal webs, (e) suitable for subglottic extension, (f) improved vocal function as well as the airway. Tracheostomy usually was not needed unless the keel reached the posterior third of glottis. This was happened in 2 cases of our subjects.

In the long-term follow-up, no adhesion or web recurrence was noticed in our subjects. This finding was consistent with previous researches [3, 22]. Although those researches reported good airway without recurrence but voice outcomes were unsatisfactory. In the current research, our subjects showed improved airway and voice quality as well. The APA revealed significant improvement in the voice quality assessed by GRBAS scale. Also, stroboscopic mucosal wave vibration showed significant improvement in 90% of subjects. The acoustic parameters measured are the following: jitter, shimmer, PPQ, and APQ showed significant improvement by decreasing after operation. Also, the HNR improved (increased) after operation. Although,

the overall F_0 did not revealed significant improvement, it was changed in both sexes nearly to the normal range direction (increased in females but decreased in males). Also, the voice pitch was decreased in congenital but increased in acquired laryngeal webs. Muscle tension (hyper-functional) dysphonia associated with ventricular hypertrophy was reported in 5 subjects. Three of the 5 subjects had responded to the behavioral readjustment voice therapy with satisfactory voice outcome. Only 2 subjects had unsatisfactory voice outcome; 1 had the same preoperative voice quality, the other got better voice but still unsatisfied. The resistant irregular/rough dysphonia in these 2 subjects can be explained by the ventricular hypertrophy grade 3 which was unresponsive to behavioral modification voice therapy. One of them showed further improvement following extensive voice therapy by high pitch voice quality. The other did not, and needed surgical excision of the hypertrophied ventricular band. Finally, 90% of our subjects have satisfactory voice outcomes. Generally speaking, ventricular hypertrophy may develop in longstanding laryngeal pathology which deprives the vocal fold from its phonatory function; the anterior laryngeal web. Patients usually compensate by searching for another anatomical level for voice production by the exhaled air. This usually occurs at the nearby structures; the ventricular bands and/or the arytenoids resulting in irregular/rough voice. The voice rehabilitation methods used in our subjects were Smith Accent method to enhance abdomino-diaphragmatic breathing during speech and attaining high-pitch voice quality. Accent method provides breath support for phonation and reduces muscle tension. Attaining high-pitch voice quality enhanced participation of the vocal folds in phonation, decreased tension and lateral compression exerted by ventricular bands, and eliminated ventricular sharing in phonation. Hence, surgical treatment of the laryngeal web with proper keel placement followed by intensive voice therapy had positive impacts on the vocal function of the larynx. This included treatment of both the underlying organic cause and the consequent functional aspect (the developed faulty/compensatory vocal behavior). None of our subjects have recurrence of the web even those with thick webs. This is different than what have been reported by Chen et al. [23]. Basically, prevention of web recurrence depends on proper fixation of the keel at the anterior commissure with optimal tension of stitches. This must be neither loose which predispose for webbing, nor too tight which make trauma with consequent webbing too. No complications were reported in our treatment. However, it had a limitation that cannot be performed for cartilaginous or annular subglottic stenosis which requires different treatment [24].

Conclusion

Endo-laryngeal excision with individually designed ePTFE keel is a successful treatment method for the anterior laryngeal web. Our design of the ePTFE keel prevents web recurrence because of perfect healing with no reaction which, in turn, has positive impact on voice outcome. This method is simple, minimally invasive and does not require laryngofissure or any special equipment. The congenital and long-standing acquired anterior laryngeal web may result in hyperfunctional dysphonia with compensatory ventricular hypertrophy which adds to the pathogenesis of the dysphonia. This requires intensive voice therapy after operation. Our treatment deals with the original organic and the secondary functional elements of the dysphonia. The expanded polytetrafluoroethylene membrane may be good alternative for silicone in laryngeal keel design after precise excision of anterior glottic web. Further researches with more subjects' number are recommended before generalization of the results.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43163-022-00273-3.

Additional file 1.

Declarations

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