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THE IMPACT OF BOTULINUM TOXIN ON VOICE QUALITY AFTER LARYNGECTOMY

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ABSTRACT

Objectives: Tracheoesophageal (TE) speech is the preferred method of voice rehabilitation after total laryngectomy; however, its effectiveness is frequently compromised by pharyngoesophageal spasm (PES). The objective of this review was to evaluate the anatomical, physiological, diagnostic, and therapeutic evidence supporting the use of botulinum toxin (BTX) for the management of PES-related TE voice dysfunction.
Methods: A narrative review of peer-reviewed English-language literature was conducted using PubMed and major scientific databases. Studies addressing pharyngoesophageal segment physiology, diagnostic assessment of PES, and clinical, acoustic, aerodynamic, and perceptual outcomes following BTX injection in laryngectomized patients were qualitatively synthesized.
Results: Across heterogeneous study designs, PES was consistently identified as a primary barrier to effective TE phonation, characterized by elevated intraluminal pressure, restricted segmental aperture, and impaired vibratory behavior. BTX injection reliably reduced PE segment hypertonicity, resulting in improved airflow dynamics, enhanced vibratory regularity, increased maximum phonation time, and improved acoustic stability. Perceptual assessments and patient-reported outcomes demonstrated significant gains in speech intelligibility, vocal effort, communicative participation, and quality of life. Additional benefits included improved prosthesis function and longevity. Adverse effects were mild, transient, and infrequent.
Conclusions: Botulinum toxin is a safe, minimally invasive, and physiologically targeted treatment for PES-related TE speech dysfunction. The convergent evidence supports its role as a first-line or adjunctive therapy for restoring voice quality and communication after total laryngectomy.

KEYWORDS
Tracheoesophageal Speech, Total Laryngectomy, Pharyngoesophageal Segment, Botulinum Toxin, Voice Rehabilitation

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Introduction

Total laryngectomy (TL) remains a central treatment for advanced laryngeal and hypopharyngeal malignancies, resulting in the removal of the laryngeal sound source and permanent redirection of breathing through a tracheostoma (Agrawal & Goldenberg, 2008; Iwai et al., 2023). The anatomical and physiological consequences of TL fundamentally alter phonation, swallowing, respiration, and quality of life, requiring patients to adopt alternative speech modalities such as esophageal speech (ES), electrolaryngeal speech (ELS), or tracheoesophageal (TE) speech (Zenga et al., 2018; Köybaşioğlu et al. 2003). Among these rehabilitative strategies, TE speech is consistently identified as providing the highest levels of intelligibility, naturalness, and communicative effectiveness, outperforming ES and ELS across perceptual, acoustic, and functional parameters (van Sluis et al., 2018). These findings explain why TE phonation has become the preferred communication method for most laryngectomized patients.

Successful TE voicing depends on pulmonary airflow transmitted through a voice prosthesis into the pharyngoesophageal (PE) segment, which serves as the vibratory source after TL. (Zhang et al., 2019). The biomechanical behavior of this segment is influenced by mucosal pliability, muscular tone, segmental relaxation, and structural symmetry - factors essential for efficient alaryngeal sound production (Dworkin et al., 1998). Videostroboscopic evaluations show that effective TE speakers demonstrate thin, well-synchronized mucosal vibration, whereas poor TE speakers exhibit thickened, redundant, and irregularly oscillating PE tissues that compromise acoustic output (Dworkin et al., 1998; Meleca et al., 2000). Acoustic investigations have correlated these vibratory deficiencies with reduced harmonic energy, instability of the fundamental frequency, and elevated turbulence, all of which contribute to diminished intelligibility and lower communicative satisfaction (van Sluis et al., 2018; Zhang et al., 2019).

One of the most frequent causes of TE speech failure is pharyngoesophageal spasm (PES), characterized by excessive tonic contraction and impaired relaxation of the pharyngeal constrictor or cricopharyngeus muscle (Blitzer et al., 1995; Kazemi et al., 2024). Radiographic studies reveal that PES induces dynamic narrowing of the PE segment during attempted phonation, limiting transsegmental airflow despite a properly functioning voice prosthesis (Dworkin et al., 1998; Blitzer et al., 1995). Manometric assessments have confirmed abnormally elevated intraluminal pressures in the PE segment among PES patients, often exceeding values needed for effective vibration and airflow transfer (Chone et al., 2009). Clinical reports indicate that PES is a leading contributor to TE speech impairment among unsuccessful speakers, representing one of the most prevalent barriers to rehabilitation (Blitzer et al., 1995). Aerodynamic evaluations further support these observations, demonstrating increased driving pressure requirements, reduced maximum phonation time, and strained or fragmented phonatory output in affected individuals (van Sluis et al., 2018; Zhang et al., 2019).

In addition to disrupting phonation, PES imposes secondary functional burdens including dysphagia, increased prosthesis leakage, and reduced prosthesis longevity, all of which further diminish post-laryngectomy quality of life (Kazemi et al., 2024; Krause et al., 2009; Braun et al., 2010). Psychological and social consequences are also considerable, as patients with limited TE function frequently report communication anxiety, diminished social participation, and increased frustration related to communicative limitations (Iwai et al., 2023). These findings highlight the clinical importance of identifying and treating PES in laryngectomized individuals.

Historically, surgical myotomy was the principal intervention for PES; however, it carries notable risks, particularly in previously irradiated or fibrotic tissues. Complications such as impaired wound healing, postoperative fistula formation, and aspiration limit the suitability of surgical management in many cases (Zenga et al., 2018; Hoffman et al., 1997). Consequently, minimally invasive alternatives have been explored, leading to the introduction of botulinum toxin (BTX) for reducing PE hypertonicity (Blitzer et al., 1995). Early studies using electromyographic guidance demonstrated that BTX effectively reduced constrictor muscle overactivity and restored TE phonation in patients who had previously failed speech rehabilitation (Terrell et al., 1995). Subsequent clinical series have reinforced these findings, reporting improvements in airflow parameters, acoustic regularity, maximum phonation time and overall speech intelligibility following BTX administration (Kazemi et al., 2024; Hamaker & Blom, 2003).

More recent studies incorporating videofluoroscopic and ultrasound-guided injection techniques have further confirmed the efficacy and precision of BTX in treating PES, even in patients with distorted anatomy from radiotherapy or repeated surgeries (Maniaci et al., 2024; Chaukar et al., 2013). Complementary literature examining TE voice mechanics, PE vibratory patterns, and the aerodynamic requirements of alaryngeal speech provides a compelling physiological explanation for BTX's impact: reduced PE tone is associated with increased segmental compliance, improved vibratory symmetry, and more efficient conversion of airflow into sound (Zhang et al., 2019; Meleca et al., 2000). Collectively, these findings support the use of BTX as a clinically valuable, minimally invasive, and widely applicable treatment for PES-related TE speech dysfunction (Zenga et al., 2018; Blitzer et al., 1995; Kazemi et al., 2024)

Given the intricate interaction between PE segment physiology, postoperative anatomy, prosthetic airflow dynamics, and patients' communicative needs, a comprehensive synthesis of the available evidence is essential. This review therefore examines anatomical, physiological, diagnostic, and therapeutic perspectives to assess the role of BTX in improving voice quality after laryngectomy. (Zenga et al., 2018; Sparks et al., 2023).

Materials and Methods

This work was conducted as a narrative review examining the role of botulinum toxin (BTX) in the management of pharyngoesophageal segment (PES) dysfunction following total laryngectomy. Given the complexity of tracheoesophageal (TE) voice production and the heterogeneity of available evidence, a qualitative synthesis approach was selected rather than a formal systematic review or meta-analysis.

A literature search was conducted using PubMed and major scientific publishing platforms, including SpringerLink, Wiley Online Library, Nature, and Elsevier (ScienceDirect). Search terms included combinations of "total laryngectomy," "tracheoesophageal speech," "pharyngoesophageal segment," "pharyngoesophageal spasm," "botulinum toxin," "botulinum neurotoxin," "voice rehabilitation," "alaryngeal speech," "pharyngeal constrictor,"and "voice prosthesis." Only peer-reviewed articles published in English and available in full text were considered. Reference lists of key publications were also screened to identify additional relevant studies.

Searches were not restricted by publication date in order to capture both early foundational studies and more recent clinical and technical advances in the diagnosis and treatment of PES dysfunction.

Studies were included if they addressed clinical outcomes following BTX injection for pharyngoesophageal segment–related tracheoesophageal speech dysfunction; physiological, biomechanical, or anatomical characteristics of the pharyngoesophageal segment relevant to TE phonation; diagnostic assessment of PES hypertonicity using radiographic, manometric, acoustic, or aerodynamic methods; determinants of TE voice quality, airflow dynamics, or vibratory behavior; or functional outcomes after laryngectomy, including voice quality, swallowing, prosthesis performance, and patient-reported measures.

Studies unrelated to total laryngectomy or pharyngoesophageal function were excluded. Publications focusing exclusively on cosmetic or non–head and neck applications of BTX were not considered unless they provided methodological insights relevant to injection techniques, toxin pharmacodynamics, or neuromuscular mechanisms applicable to PES treatment.

Eligible studies were reviewed in full, and data were extracted using a structured qualitative framework. Extracted variables included study design, sample size, patient demographics, oncologic treatment history (including prior radiotherapy), type of tracheoesophageal puncture (primary or secondary), diagnostic modalities used to identify PES dysfunction, and details of BTX formulation, dosage, and injection technique.

Voice-related outcomes and functional measures were also recorded, including instrumental, perceptual, and patient-reported parameters. When multiple publications reported overlapping patient populations or

similar outcome measures, greater emphasis was placed on studies demonstrating methodological rigor, objective physiological assessment, and transparent outcome reporting.

Diagnostic approaches varied across studies and included videofluoroscopy, videostroboscopy, computerized or conventional manometry, acoustic and aerodynamic analyses, and perceptual evaluations such as intelligibility ratings and voice-related quality-of-life instruments.

Because BTX treatment aims to reduce hypertonicity of the PES, particular attention was given to physiological variables expected to change following injection, including intraluminal pressure, segmental aperture, vibratory regularity, airflow resistance, and spectral stability.

Voice outcomes were categorized into instrumental and perceptual domains to facilitate comparison across heterogeneous methodologies. Instrumental outcomes included maximum phonation time, cepstral peak prominence, harmonic-to-noise ratio, perturbation measures, PES pressure metrics, and radiographic assessments of segmental narrowing. Perceptual outcomes encompassed conversational fluency, vocal effort, intelligibility, ease of phonation, and patient-reported communicative function. Studies reporting prosthesis leakage or longevity were also included, as these parameters indirectly reflect PES tone and transsegmental airflow resistance.

Given the heterogeneity of study designs, outcome measures, and diagnostic techniques, findings were synthesized narratively, with emphasis placed on recurring patterns, convergent physiological mechanisms, and consistency of clinical effects across independent sources rather than on numerical pooling or meta-analytic comparison.

Ethical approval was not required, as this review analyzed only previously published studies and did not involve new human subject research or the collection of original clinical data.

Results

The analysis of the selected literature revealed a high degree of consistency across clinical, radiologic, acoustic, and physiological studies examining the effects of botulinum toxin (BTX) on voice restoration after total laryngectomy (Zenga et al., 2018; Kazemi et al., 2024). Studies varied widely in design and sample size, yet converged on several core findings regarding pharyngoesophageal spasm (PES) as a primary barrier to tracheoesophageal (TE) phonation and the therapeutic role of BTX in alleviating this dysfunction. (Blitzer et al., 1995)

Across the reviewed publications, patients with PES consistently exhibited similar anatomical and physiological abnormalities. Videostroboscopic studies demonstrated markedly reduced vibratory amplitude, irregular mucosal oscillation, and impaired symmetry of the pharyngoesophageal (PE) segment during phonation attempts, confirming that excessive muscle tone restricts the segment's ability to function as an effective neoglottis (Meleca et al., 2000; Meleca et al., 2000). Complementary videofluoroscopic investigations revealed abrupt or persistent narrowing of the PE segment during expiration and attempted phonation, often resulting in near-complete obstruction despite a properly functioning voice prosthesis (Chaukar et al., 2013; Bandi et al., 2024). These dynamic imaging findings corresponded closely with patient-reported symptoms such as strained phonation, vocal breaks, short phonation bursts, and inability to sustain continuous airflow through the prosthesis. (Maniaci et al., 2024)

Manometry provided further objective evidence for the role of hypertonicity in TE speech failure. Studies by Köybaşıoğlu and Chone demonstrated that patients with PES show substantially elevated intraluminal pressures relative to successful TE speakers, confirming that malfunction arises predominantly from excessive resistance at the PE level rather than from airflow insufficiency or prosthesis malfunction (Köybaşioğlu et al., 2003; Chone et al., 2009). Following BTX injection, these studies consistently documented significant decreases in segmental pressure, often paralleling immediate or near-immediate observable improvements in TE voice quality. The reduction in pressure was accompanied by increased ease of phonation, greater airflow continuity, and improved ability to initiate voicing, supporting the direct physiological effect of BTX on constrictor muscle relaxation. (Chone et al., 2009; Hamaker & Blom, 2003)

Acoustic assessments mirrored these physiological improvements. Caetano reported increases in cepstral peak prominence and improved harmonic-to-noise ratios after BTX injection, indicating enhanced vibratory regularity and a more periodic acoustic signal (Caetano et al., 2025). Lightbody's findings reinforced this, showing that patients who had previously been unable to generate intelligible TE speech achieved measurable acoustic phonation with improved spectral stability following treatment (Lightbody et al., 2015). Kazemi similarly demonstrated clinically meaningful acoustic and aerodynamic gains, even in populations heavily affected by fibrosis and radiation-induced scarring (Kazemi et al., 2024). Across these studies,

maximum phonation time (MPT) improved significantly, suggesting that BTX not only facilitates phonation initiation but also allows patients to maintain airflow more efficiently through a less resistant PE segment. (Kazemi et al., 2024; Hamaker & Blom, 2003).

Perceptual and functional outcomes also showed substantial gains following BTX administration. Improvements in speech intelligibility, vocal fluency, and conversational participation were reported in multiple studies (Blitzer et al., 1995; Lightbody et al., 2015; Chone et al., 2008). Patients frequently described reduced strain and effort during communication, and many regained the ability to sustain conversational voice for the first time since laryngectomy. (Blitzer et al., 1995; Lightbody et al., 2015). In some instances, BTX restored TE phonation in patients who had been entirely aphonic despite adequate prosthesis positioning and airflow, demonstrating its critical role in reversing otherwise refractory PES-related dysfunction (Blitzer et al., 1995; Lightbody et al., 2015). The psychosocial impact of these improvements was significant; qualitative research highlighted that successful restoration of TE voice contributes to improved self-perception, social reintegration, and emotional well-being (Iwai et al., 2023; Iype et al., 2020).

Several studies explored secondary benefits of BTX treatment. Krause reported that reducing PE muscle tone also prolonged the longevity of indwelling prostheses by reducing back-pressure and minimizing leakage around the device (Krause et al., 2009). This finding underscores the multifaceted influence of PE tone on both phonation and prosthesis function. Additionally, improvements in swallowing comfort and reduction of spasm-related discomfort were reported in some series, although these effects were secondary to vocal outcomes (Zenga et al., 2018; Arenaz Búa et al., 2018)

Across the entire corpus of studies, adverse effects of BTX were minimal. Reported complications included transient dysphagia, mild globus sensation, or temporary aspiration episodes, all of which resolved spontaneously without long-term consequences (Blitzer et al., 1995; Lightbody et al., 2015). No study documented serious or lasting adverse reactions, and in contrast to surgical myotomy, BTX injections carried significantly lower morbidity, making them particularly advantageous in patients with extensive fibrosis or prior radiation exposure. (Blitzer et al., 1995; Hoffman et al., 1997)

In summary, the collective evidence demonstrates that BTX reliably reduces hypertonicity of the PE segment, producing measurable improvements in pressure dynamics, vibratory function, acoustic stability, phonation duration, speech intelligibility, and patient-reported communication ease. These benefits were observed across diverse patient populations, injection techniques, and clinical contexts, firmly establishing BTX as a highly effective, low-risk therapeutic option for managing PES and improving TE voice outcomes after laryngectomy. (Chone et al., 2009; Lightbody et al., 2015)

The overall physiological, acoustic, aerodynamic, perceptual, and functional effects of botulinum toxin injection on PES-related tracheoesophageal voice dysfunction are summarized in Table 1.

Discussion

The findings of this review demonstrate consistent, cross-disciplinary evidence that botulinum toxin (BTX) represents a highly effective, physiologically targeted intervention for restoring tracheoesophageal (TE) phonation in post-laryngectomy individuals affected by pharyngoesophageal spasm (PES). (Zenga et al., 2018; Blitzer et al., 1995). Across instrumental and perceptual outcome domains, BTX was shown to exert clear beneficial effects by reducing constrictor muscle hypertonicity, improving vibratory function, and enhancing airflow through the pharyngoesophageal (PE) segment. (Chone et al., 2009)

The results of multiple videofluoroscopic, stroboscopic, and manometric studies converge on a central principle: PES disrupts TE voice because the hypertonic PE segment fails to permit adequate airflow or vibratory oscillation necessary for sound generation (Meleca et al., 2000; Chone et al., 2009; Maniaci et al., 2024). Regardless of surgical technique or prosthetic device, when the PE segment remains constricted, the neoglottic source cannot sustain oscillation. This phenomenon has been repeatedly confirmed in patients with otherwise appropriate pulmonary effort, adequate tracheoesophageal puncture, and well-functioning prostheses. (Blitzer et al., 1995; Lightbody et al., 2015) Consequently, BTX's mechanism, temporary chemodenervation of the pharyngeal constrictor musculature, directly addresses the dominant physiological barrier to TE phonation. (Blitzer et al., 1995; Zalvan et al., 2004)

BTX consistently reduced resting and dynamic PE pressures in manometric studies, demonstrating its capacity to normalize pressure patterns to levels compatible with vibratory function. (Köybaşioğlu et al., 2003; Chone et al., 2009) From a clinical perspective, these findings suggest that the presence of residual PE tone should not preclude BTX treatment, as meaningful communicative improvement can occur without complete physiological normalization. This physiological responsiveness was particularly evident in patients with

radiation-induced fibrosis, in whom PES hypertonicity is often refractory to behavioral therapy. These patients often represent the most complex subset of TE speakers, yet BTX produced significant improvements even in this population. (Kazemi et al., 2024)

Table 1. Effects of botulinum toxin (BTX) injection on PES-related tracheoesophageal voice dysfunction, based on a qualitative synthesis of the reviewed literature.

Outcome domain	Pre-BTX findings	Post-BTX effects	Clinical significance
PE muscle tone	Hypertonicity and spasm	Reduced tonic contraction	Restoration of functional neoglottic compliance
Intraluminal pressure	Elevated PE pressures	Significant pressure reduction	Improved airflow transmission
Segmental vibration	Irregular, stiff, asymmetric oscillation	Increased vibratory regularity and symmetry	More stable sound generation
Aerodynamic efficiency	High driving pressure; short MPT	Increased airflow efficiency; prolonged MPT	Sustained phonation
Acoustic stability	Low CPP; reduced HNR; high perturbation	Improved CPP and harmonic structure	Enhanced voice quality
Speech intelligibility	Strained, fragmented, or aphonic speech	Improved fluency and intelligibility	Functional verbal communication
Vocal effort	High perceived effort	Reduced phonatory strain	Improved conversational endurance
Patient-reported outcomes	Communication anxiety; limited participation	Improved QoL and social engagement	Psychosocial rehabilitation
Prosthesis performance	Increased leakage; shortened device lifespan	Reduced back-pressure; prolonged longevity	Lower maintenance burden
Safety profile	-	Mild, transient dysphagia or globus	Favorable risk-benefit ratio

A major strength of BTX therapy demonstrated across the literature is that it improves multiple aspects of voice quality, not merely the ability to generate sound. (Caetano et al., 2025) Acoustic analyses revealed enhancement of harmonic structure, increases in cepstral peak prominence (CPP), reductions in jitter and shimmer, improved spectral stability, and lengthening of maximum phonation time. These findings underscore that BTX does not merely eliminate spasm but creates more favorable aerodynamic and biomechanical conditions for oscillation. The improved acoustic regularity observed after BTX aligns with stroboscopic evidence showing greater mucosal pliability and more synchronous vibration, which together contribute to a cleaner signal and greater listener acceptability. (Meleca et al., 2000; Caetano et al., 2025)

Equally important are the perceptual and psychosocial outcomes. Multiple studies documented marked improvements in speech fluency, intelligibility, and overall communicative ease. Patients who previously experienced short, strained, or fragmented speech production reported substantial reductions in effort and increases in conversational endurance. (Iwai et al., 2023; Blitzer et al., 1995; Lightbody et al., 2015). In some cases, BTX restored TE phonation in individuals who had been completely aphonic despite exhaustive rehabilitation. (Lightbody et al., 2015) The psychological significance of regaining functional voice after prolonged inability to communicate cannot be overstated; improvements were frequently accompanied by increased confidence, reduced communication anxiety, and enhanced social integration. (Iwai et al., 2023; Cocuzza et al., 2013)

The present review also provides important insights into the comparative value of BTX versus surgical interventions such as cricopharyngeal myotomy. While myotomy had historically served as the primary

treatment for PES, its effectiveness in irradiated, fibrotic, or surgically complex tissues is limited, and the risk profile significantly exceeds that of BTX injections. (Blitzer et al., 1995; Watson et al., 2020) BTX offers a minimally invasive, repeatable, and reversible option with minimal discomfort, negligible downtime, and low complication rates. Across all reviewed studies, adverse effects of BTX were minor and transient, most commonly brief dysphagia or mild globus sensation, with no reports of serious or lasting complications. This stands in stark contrast to postoperative fistula formation, swallowing impairment, and healing difficulties associated with myotomy in previously irradiated patients. (Blitzer et al., 1995; Hoffman et al.,1997; Chone et al., 2005)

Another clinically relevant observation is that BTX can improve prosthesis performance indirectly by lowering PE segment resistance. Reduced constriction around the tracheoesophageal puncture decreases mechanical stress on the prosthesis, thereby reducing leakage and prolonging device lifespan. This effect, although secondary to vocal outcomes, underscores the broader rehabilitative value of BTX in laryngectomy care. (Krause et al., 2009)

A noteworthy dimension of the reviewed literature is the diversity of BTX delivery techniques including EMG-guided, ultrasound-guided, fluoroscopy-guided, and endoscopic. All methods demonstrated reliable outcomes, suggesting that accurate muscle targeting, rather than the specific imaging modality, is the key determinant of success. The availability of multiple approaches also enhances BTX's adaptability across clinical settings, including outpatient environments where more invasive procedures would be impractical. (Terrell et al., 1995; Maniaci et al., 2024; Chaukar et al., 2013)

Despite the strengths of the evidence base, some limitations merit discussion. Many BTX studies involved small sample sizes or lacked long-term follow-up. (Zenga et al., 2018) The duration of BTX benefit varied among patients, ranging from several months to over a year, reflecting individual differences in anatomy, fibrosis, toxin responsiveness, and dosing. There remains a need for standardized dosing protocols and controlled comparative studies to identify optimal timing, injection pattern, and follow-up procedures. (Blitzer et al., 1995) Moreover, while BTX efficacy is well established in PES, its role in other post-laryngectomy voicing disorders, such as segmental vibration asymmetries not caused by hypertonicity, remains less defined. (Meleca et al., 2000)

Nevertheless, the convergence of findings across independent studies, methodologies, and patient populations supports a compelling conclusion: BTX is a highly effective treatment for PES-related TE speech dysfunction, improving both physiological parameters and patient-reported communication outcomes. Its minimally invasive nature, favorable safety profile, and restorative impact on voice quality make BTX a cornerstone of modern post-laryngectomy rehabilitation. (Blitzer et al., 1995; Lightbody et al., 2015)

Conclusions

Botulinum toxin has emerged as a transformative therapeutic tool for improving voice quality after total laryngectomy, particularly in individuals whose tracheoesophageal phonation is compromised by pharyngoesophageal spasm. Across a diverse body of clinical and physiological studies, BTX consistently demonstrated its ability to decrease hypertonicity of the pharyngeal constrictor muscles, restore airflow through the PE segment, enhance vibratory function, and significantly improve acoustic and perceptual aspects of TE speech. These improvements extend beyond measurable vocal parameters, contributing meaningfully to patients' communicative independence and psychosocial well-being. (Blitzer et al., 1995; Chone et al., 2009)

BTX offers substantial advantages over surgical interventions, including lower morbidity, reversibility, and suitability for patients with radiation-induced fibrosis or complex anatomical alterations. Its capacity to prolong prosthesis longevity further underscores its multifaceted rehabilitative value.

Given the strong convergence of evidence, BTX should be considered a first-line treatment for PES-related TE voice failure, either as a primary intervention or as a rescue therapy in cases where conventional rehabilitation strategies prove insufficient. Future research should aim to establish standardized dosing protocols, refine injection techniques, and evaluate long-term outcomes to optimize treatment pathways.

Overall, BTX represents a safe, effective, and highly impactful modality for restoring voice quality and communication function after total laryngectomy.

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