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Long-term acoustic outcomes, perceptual voice assessment and voice-related quality of life in transgender women undergoing Wendler glottoplasty: a single-center experience

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ABSTRACT:

Introduction: Since the voice is uniquely tied to gender identity, it constitutes a considerable factor in the transition process of transgender individuals.

Aim: We aimed to analyze the long-term durability of Wendler glottoplasty (WG) acoustic outcomes in transgender women and juxtapose the objective results with voice-related quality of life (QoL) assessment and gender perception in telephone communication.

Methods: We retrospectively reviewed the records of 7 transgender women who underwent WG, self-assessed their voice-related QoL, and participated in the telephone test. Long-term results were compared with data acquired preoperatively and at short-term follow-up, as well as with the age-matched control group of 7 cisgender males and 7 cisgender females. The speech samples of transfeminine individuals and cisgender controls were judged by 64 cisgender listeners.

Results: After an average of 18.63 months, a persistent, significant increase in fundamental frequency, speaking fundamental frequency, and lower limit of the frequency range of spoken voice was observed, with the values being comparable to cisgender female controls. Despite a significant long-term improvement in the emotional domain of the Voice Handicap Index, the remaining voice-related QoL scores deteriorated compared to the short-term evaluation. The gender of transfeminine individuals was significantly more often incorrectly attributed compared to cisgender controls. The percentage of voice ratings as a female was not correlated with the acoustic measures, self-assessed vocal femininity, and satisfaction with WG results.

Conclusions: Despite the long-term durability of acoustic changes after WG, the gradual reduction of the initially improved voice-related QoL suggests the need for multidisciplinary management. The acoustic measures cannot guarantee voice attribution as female by external evaluators, indicating the beneficial role of perceptual assessment in analyzing WG outcomes.

KEYWORDS: acoustic analysis, gender perception, phonosurgery, pitch elevation, voice feminization

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ABBREVIATIONS

F0 – fundamental frequency
F1 – first formant frequency
F2 – second formant frequency
F3 – third formant frequency
F4 – fourth formant frequency
FFs – formant frequencies
QoL – quality of life
SD – standard deviation
sF0 – speaking fundamental frequency
ST – semitones
TWVQ – Trans Women Voice Questionnaire
VAS – Visual Analog Scale
VF – vocal fold
VHI-30 – Voice Handicap Index-30
V-RQOL – Voice-Related Quality of Life questionnaire
VT – voice therapy
WG – Wendler glottoplasty

INTRODUCTION

Voice as a secondary sexual characteristic allows the individual's gender attribution within the first 200 ms of speech [1]. Since the voice is uniquely tied to one's gender identity, it constitutes a considerable factor in the transition process of transgender individuals. Although in transmasculine individuals, satisfactory voice masculinization is achieved through testosterone hormone therapy and speech training [2], in transgender women, estrogen therapy applied after puberty does not perceivably alter the pitch [3, 4]. The incongruence of the masculine voice with the female gender identity can be mitigated through voice therapy (VT) or phonosurgical interventions aiming at increasing vocal folds' (VFs) tension, reducing the VFs' mass, or decreasing their vibratory length [5].

In our previous study [6], we achieved satisfactory short-term results through the reduction of the effective vibratory length of the VFs using the Wendler glottoplasty (WG) technique. The procedure consists of endoscopic de-epithelialization (with sharp microinstruments or CO_2 laser) and subsequent suturing of the anterior one-third of the VFs, which creates an anterior glottal synechia, leading to the retropositioning of the anterior commissure [5–7]. The surgical voice feminization aims to raise the fundamental frequency (F0), accountable for up to 50-60% of the perceived vocal femininity [8]. While the F0 characteristic for the adult male population amounts to 80–145 Hz, in adult females, it prevailingly ranges from 165 Hz to 225 Hz [7, 9]. The F0 increase above the threshold range of 145 to 165 Hz contributes to a female gender perception [7, 9, 10]. Nevertheless, the values of the speaking fundamental frequency (sF0) and formant frequencies (FFs), as well as resonance, intonation, pitch inflection patterns, articulation, prosody, and nonverbal communication, might contribute to ultimate gender attribution [5, 11, 12].

Despite the VT and surgical pitch elevation, some transgender women report persistent exposure to stigmatization due to gender misattribution during telephone conversations with noticeable irritation or hesitation of their interlocutors [7, 13]. The gender misperception over the telephone might partially stem from the lack of visual information since physical appearance has been shown to considerably influence the perception of vocal femininity [7, 14]. Notably, quantification of gender perception in telephone communication performed by Meister et al. revealed that merely 40% of transfeminine individuals were perceived as female by most listeners, despite the median F0 of their voices reaching the female frequency range [7]. Accordingly, the evaluation of transgender women's voices by external listeners, alongside objective acoustic analysis and self-assessment of the voice-related quality of life (QoL), might constitute a valuable instrument for evaluating the effectiveness of voice feminization procedures [5, 7].

Additionally, the overall satisfaction with the procedure might be influenced by the persistence of the achieved elevated pitch in the long term. The gradual reduction of the initially obtained F0 value observed by several authors [15, 16] might be partially attributed to the pulling of the posterior edge of the anterior glottal web by the vibratory portions of the VFs, which might lead to a partial or complete anterior glottal dehiscence.

AIM

The aims of our study were to analyze the long-term acoustic WG outcomes in transfeminine individuals to reflect the durability of the induced vocal changes, as well as juxtapose the objective results with the self-assessed voice-related QoL and perceptual voice evaluation in telephone communication, considerably contributing to the overall procedural success.

MATERIALS AND METHODS

Study group

Following Institutional Review Board approval, data were collected retrospectively for 7 transgender women who underwent WG for voice feminization in the Department of Otorhinolaryngology and Oncological Laryngology in Zabrze, Medical University of Silesia in Katowice, Poland, between November 2022 and September 2023. All individuals met the following inclusion criteria: 1) native speaker of Polish language, 2) at least 18 years of age, 3) established diagnosis of gender dysphoria and female gender identity, 4) the lack of preexisting vocal pathology, 5) completing a follow-up survey regarding the long-term postoperative voice-related QoL and satisfaction with the procedure's results, 6) participation in the perception telephone test. All subjects provided informed consent before being enrolled in the study.

Control group

The control group consisted of 7 cisgender male and 7 cisgender female speakers of the same age (in the range of ±3 years, and at least 18 years of age) as the included transgender individuals. Therefore, each transgender individual had one control cisgender male participant and one control cisgender female participant

matched by age. The similarity between transgender individuals and cisgender controls was considered crucial due to the well-documented age-related changes occurring in the F0 and their presumed impact on the perceived speaker gender [17]. All control participants were native speakers of the Polish language with a negative history of hearing, voice, and neurological disorders, carcinoma of the head and neck, and smoking tobacco for the past 5 years. All individuals took part in the perception telephone test and provided informed consent before being enrolled in the study.

Speech samples

Each of the 21 speakers included in the study was asked to articulate the same sentence, "Dzień dobry, tak brzmi mój głos po operacji" ("Good morning, this is what my voice sounds like after the surgery") twice. Participants were asked to use their habitual voices. Only the second attempt was applied for the test. All recordings were made over the telephone during a scheduled recording session to better reflect the conditions present in everyday life and to approximate a realistic scenario in which the gender of the transfeminine individuals is judged based on the sound of their voice during the telephone conversation.

Voice data collection procedures

An experimental audiotape was created by randomizing the order of all transgender and control subject voice samples. Intralistener variability was taken into consideration by repeating two control and two patient voice samples an additional time at random within the audiotape. Consecutive recordings of the above-mentioned 4 speakers were avoided. Each sample was followed by an 8-second response time.

Listener participants

Twenty-seven male and thirty-seven female cisgender undergraduate medical students participated in the perception telephone test. All listeners were native speakers of the Polish language, reported no hearing impairment, and were unaware of the nature and objectives of the study, as well as its participants.

Listening procedure

All listeners were seated in a quiet room (with an ambient noise level of 50 dB or less) in groups of up to 25 individuals, with each participant no further than 3 meters from a speaker. Listeners were instructed to attribute a male or a female gender to each speaker, estimate their age with an accuracy of 5 years (e.g., 25, 30, 35, 40 years, etc.), and determine whether each voice is euphonic (normal) or dysphonic (hoarse, strained, weak, breathy, etc.). The judgments on age and the presence of dysphonia were intended to distract the listeners from the investigators' primary interest in gender attribution. The experimental audiotape was presented only once. The listeners were instructed to score each sample immediately after the presentation on a predesigned scoring sheet while using their own judgment and not consulting with other participants.

Acoustic analysis

An objective acoustic analysis of the voice samples was performed for all transfeminine individuals and cisgender controls based on the following parameters: 1) fundamental frequency (F0, in Hz); 2) formant frequencies (FFs, in Hz) – first (F1), second (F2), third (F3), and fourth (F4) formant frequency; 3) speaking fundamental frequency (sF0, in Hz); and 4) upper and lower limit of the frequency range of spoken voice (in Hz). To evaluate F0, patients were asked to prolong the vowel /a/ at a comfortable pitch and loudness for approximately 10 s. For transfeminine individuals, the mean parameter values (collected during the long-term perception telephone test) were compared with the data acquired in the preoperative and initial postoperative period (during the first follow-up visit 6 weeks after WG), described in detail in our previous report [6]. Additionally, for transgender women, the differences in F0, sF0, and frequency range of spoken voice between the preoperative, short-term postoperative, and long-term postoperative periods were calculated in semitones (ST). Acoustic analysis of voice recordings was performed using the PRAAT program (Paul Boersma and David Weenink, University of Amsterdam, Netherlands).

Voice-related quality of life and patient satisfaction questionnaires

To take into account subjective patient-reported outcome measures, all transfeminine individuals were asked to complete a survey consisting of the following questionnaires regarding the impact of the patient's current voice on the QoL and their subjective satisfaction with the long-term WG results:

1. The Voice Handicap Index-30 (VHI-30) questionnaire consists of 30 questions categorized into three domains assessing the physical, functional, and emotional aspects of the voice disorder. Each question item is scored on a 5-point scale with "0" representing "never", "1" – "almost never", "2" – "sometimes", "3" – "almost always", and "4" – "always". Higher VHI-30 scores reflect greater vocal difficulties, while a cut-off score of 20 points was determined to identify voice-related disability [18].

2. Voice-Related Quality of Life (V-RQOL) questionnaire measures the subjective burden elicited by dysphonia and its impact on patient QoL. Question items are distributed across two subscales: social-emotional (items 4, 5, 8, and 10) and physical functioning (items 1, 2, 3, 6, 7, and 9) [19]. The overall V-RQOL score can range from 10 (excellent) to 50 (poor), reflecting the intensity of vocal interference with daily activities. Additionally, the patients are asked to determine whether they consider the overall quality of their voice to be "poor", "fair", "good", or "very good".

3. The Trans Women Voice Questionnaire (TWVQ) constitutes a validated patient-reported outcome measure specific for transgender women, which facilitates the self-assessment of vocal femininity, the intensity of voice-related difficulties, and the extent to which the voice affects the psychosocial aspects of daily routines [20]. Each of the 30 question items is scored

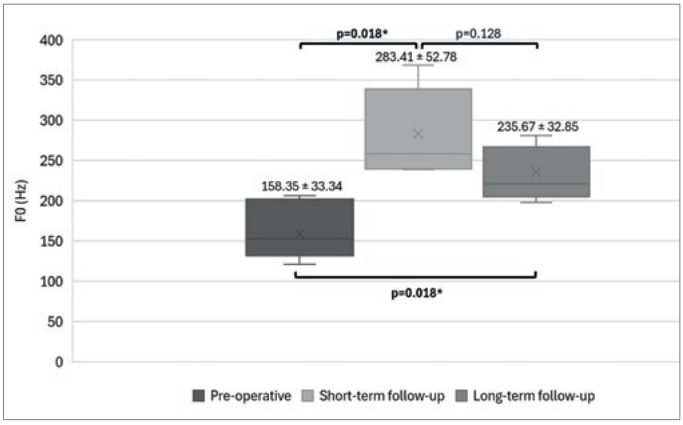

Fig. 1. Changes in mean fundamental frequency values among transgender women between the three evaluated time points.

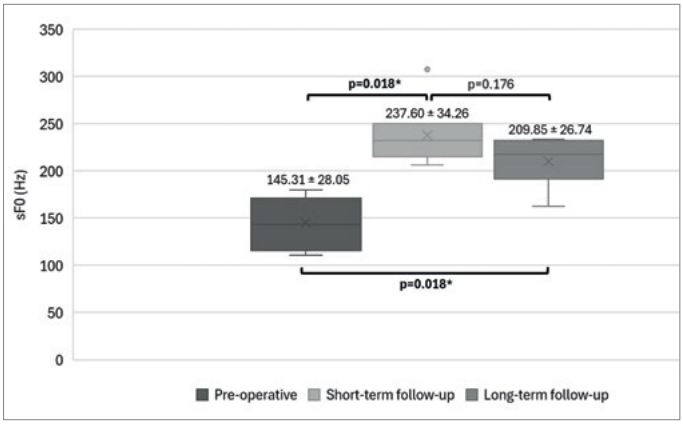

Fig. 2. Changes in mean speaking fundamental frequency values among transgender women between the three evaluated time points.

on a 4-point scale with "1" representing "never or rarely", "2" – "sometimes", "3" – "often", and "4" – "usually or always". Additionally, the patients are asked to provide an overall rating of their current voice and what their ideal voice would sound like by selecting one of the following statements: "very female", "somewhat female", "gender neutral", "somewhat male", or "very male" [20]. The overall TWVQ score can range from 30 to 120 points, where lower values indicate greater satisfaction with one's voice and its positive impact on the QoL [20].

4. The 10-cm Visual-Analog Scale (VAS) was applied to enable a) the self-assessment of the vocal femininity (with "0" representing "very masculine voice", while "10" – "very feminine voice"), and b) rating the subjective satisfaction with the procedure's results (with "0" representing "very dissatisfied", while "10" – or "very satisfied", respectively).

5. Furthermore, the transfeminine individuals were asked to provide additional information regarding 1) smoking tobacco after surgery, 2) VT attendance before or after WG, 3) undergoing other voice feminization procedures, and 4) whether they considered their current voice a) more feminine, b) hoarser, c) or weaker compared to the preoperative period. Moreover, to more accurately evaluate the patient difficulties regarding telephone communication, transgender women were asked to assess on a 5-point scale (with "0" representing "never", "1" – "almost never", "2" – "sometimes", "3" – "almost always", and "4" – "always") how often during telephone conversations 1) they are addressed as "Mr.", 2) they notice irritation of their interlocutors due to the sound of their voice, 3) they notice uncertainty or hesitation of their interlocutors due to the sound of their voice.

Statistical analysis

Wilcoxon signed-rank tests were used to assess differences between the evaluated time points. The comparison of two independent samples was performed using the Mann-Whitney *U* test. The relationship between the parameters was assessed using Spearman's rho correlation coefficient.

To compare the evaluation of the speaker's gender based on two repeated control and two patient voice samples, a Cochran's Q test (a non-parametric test used to check the homogeneity of the result proportions between at least two groups compared in terms of the dependent variable expressed on a dichotomous scale) was performed. Differences in the percentage of incorrectly assigned gender in the three groups (transfeminine individuals, cisgender female controls, and cisgender male controls) were examined using Pearson's chi-squared test.

The results were considered statistically significant at $p<0.05$. All analyses were performed using Statistica 13.3 software (StatSoft Polska, Krakow, Poland).

RESULTS

A total of 7 transfeminine individuals with a mean age of 36.71 years (standard deviation [SD] = 10.82), alongside 7 age-matched cisgender female and 7 cisgender male controls, were included.

Preoperative *vs.* short-term postoperative evaluation

During the first follow-up visit 6 weeks after WG, a significant F0 and sF0 increase of 125.06 Hz and 92.29 Hz, respectively, was observed ($p = 0.018$), which represented an average F0 and sF0 rise amounting to 10.15 ST and 8.66 ST, respectively (Fig. 1.–2.). No significant differences were found between the mean pre- and postoperative FFs values and the mean frequency range of spoken voice. Additionally, the mean upper limit of the frequency range of spoken voice did not change considerably after WG ($p = 0.31$). Contrarily, the mean lower limit of the frequency range of spoken voice rose by 79,94 Hz ($p = 0.018$). Detailed data regarding the acoustic analysis results are presented in Tab. I.

Regarding the voice-related QoL, the mean overall VHI-30 score significantly improved after WG, decreasing by 23.86 points ($p = 0.028$). A significant improvement was found in the emotional domain of VHI-30, in which a mean decrease of 16.57 points was observed ($p = 0.018$). Contrarily, the mean scores in the functional and physical domains of VHI-30 did not change significantly ($p = 0.091$ and $p = 0.447$, respectively). Moreover, the mean score in the V-RQOL questionnaire significantly improved after WG, decreasing by 12.86 points ($p = 0.028$). Additionally, significant

Tab. I. Acoustic analysis of the voice among transgender women at three evaluated time points.

PARAMETER	PRE-OPERATIVE (1)		SHORT-TERM FOLLOW-UP (2)		LONG-TERM FOLLOW-UP (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)	p-VALUE (2) *vs* (3)
	MEAN	SD	MEAN	SD	MEAN	SD			
F0 (Hz)	158.35	33.34	283.41	52.78	235.67	32.85	**0.018***	**0.018***	0.128
sF0 (Hz)	145.31	28.05	237.60	34.26	209.85	26.74	**0.018***	**0.018***	0.176
F1 (Hz)	683.40	156.82	567.39	191.78	820.60	96.18	0.398	0.091	**0.018**
F2 (Hz)	1294.91	143.04	1393.13	354.79	1375.44	147.96	0.866	0.237	0.612
F3 (Hz)	2781.07	477.61	2773.15	449.27	2474.58	330.04	0.735	0.176	0.237
F4 (Hz)	3764.58	288.74	3634.94	258.56	3851.72	304.88	0.499	0.398	0.310
Lower limit of the frequency range of spoken voice (Hz)	90.45	21.96	170.39	55.12	159.02	17.14	**0.018***	**0.018***	0.735
Upper limit of the frequency range of spoken voice (Hz)	280.65	143.52	341.62	78.52	319.40	65.24	0.310	0.310	0.735
Frequency range of Spoken voice (ST)	18.18	9.68	12.47	5.87	11.85	2.81	0.499	0.128	0.866

SD – standard deviation; F0 – fundamental frequency; sF0 – speaking fundamental frequency; F1 – first formant frequency; F2 – second formant frequency; F3 – third formant frequency; F4 – fourth formant frequency; Hz – Hertz; ST – semitones; *p<0.05.

differences were observed in the self-assessment of the overall voice quality between the preoperative period and short-term follow-up evaluation (p = 0.043). The detailed data regarding the voice-related QoL evaluation are presented in Tab. II.–III., and in Fig. 3.–4.

Preoperative *vs.* long-term postoperative evaluation

The mean interval from WG to the long-term follow-up evaluation for transfeminine individuals amounted to 18.63 months (SD = 3.15). Compared to the preoperative period, the mean F0 and sF0 increased by 77.32 Hz and 64.54 Hz, respectively (p = 0.018), which corresponded to an average F0 and sF0 increase of 7.06 ST and 6.52 ST, respectively. Similarly to the short-term postoperative assessment, the mean values of FFs, the mean frequency range of spoken voice, and the upper limit of the frequency range did not change significantly during the long-term follow-up compared to the preoperative period. Contrarily, a significant increase in the lower limit of the frequency range of spoken voice by 68.57 Hz was observed (p = 0.018).

Regarding the voice-related QoL, a significant change compared to the preoperative period was found solely in the emotional domain of VHI-30, in which a mean decrease of 14 points was observed (p = 0.028). The mean overall V-RQOL and VHI-30 scores, as well as the mean score in the functional and physical domains of VHI-30, did not change significantly in the long-term follow-up compared to the preoperative period (Tab. II.) (Fig. 3.). Additionally, the differences in the self-assessment of the overall voice quality between the preoperative and long-term follow-up evaluation did not reach statistical significance (p = 0.273) (Tab. III.) (Fig. 4.).

Short-term *vs.* long-term postoperative evaluation

The analysis comparing the results of the short-term and long-term postoperative assessment revealed significant changes solely in the F1 value, which increased by 253.21 Hz (p = 0.018). The values of the remaining parameters (F0, sF0, other FFs, the mean frequency range of spoken voice, the lower and upper limit of the frequency range, and scores in the applied voice-related QoL questionnaires) did not change significantly. Contrarily, significant

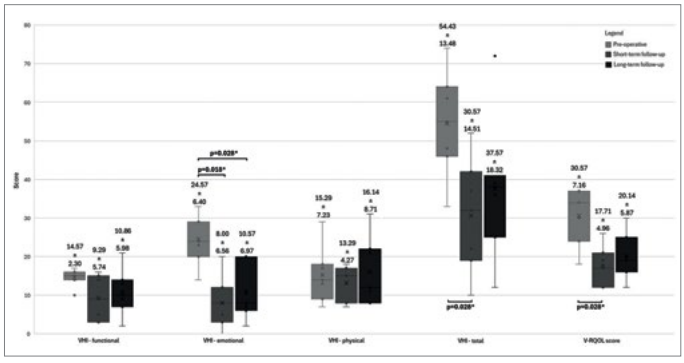

Fig. 3. Voice-related quality of life assessment in transgender women at three evaluated time points.

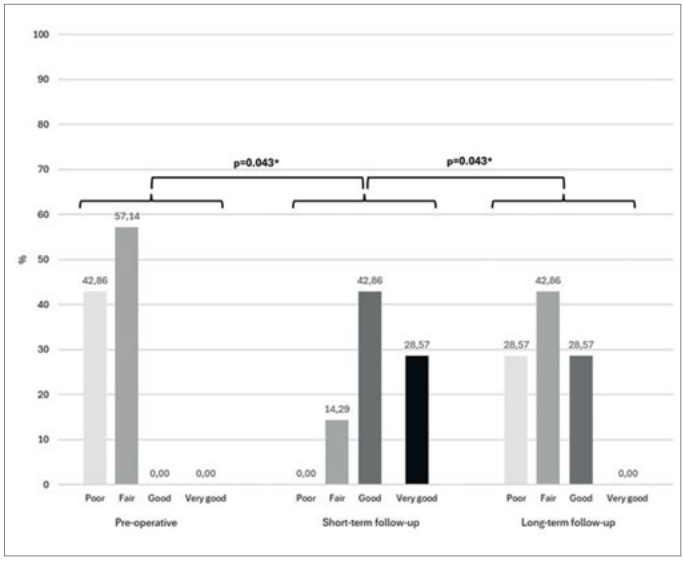

Fig. 4. Self-assessed overall voice quality in transgender women at three evaluated time points. The self-evaluation of voice quality in the V-RQOL questionnaire was not completed by one transfeminine individual (no. 7) in the short-term follow-up assessment

differences were observed in the self-assessment of the overall voice quality between short-term and long-term postoperative evaluation (p = 0.043) (Tab. III.) (Fig. 4.).

Tab. II. Voice-related quality of life assessment in transgender women at three evaluated time points.

PARAMETER	PRE-OPERATIVE (1)		SHORT-TERM FOLLOW-UP (2)		LONG-TERM FOLLOW-UP (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)	p-VALUE (2) *vs* (3)
	MEAN	SD	MEAN	SD	MEAN	SD			
VHI – total	54.43	13.48	30.57	14.51	37.57	18.32	**0.028***	0.176	0.237
VHI – functional	14.57	2.30	9.29	5.74	10.86	5.98	0.091	0.249	0.554
VHI – emotional	24.57	6.40	8.00	6.56	10.57	6.97	**0.018***	**0.028***	0.463
VHI – physical	15.29	7.23	13.29	4.27	16.14	8.71	0.447	0.866	0.499
V-RQOL score	30.57	7.16	17.71	4.96	20.14	5.87	**0.028***	0.091	0.447

SD – standard deviation; VHI – Voice Handicap Index; V-RQOL – Voice-Related Quality of Life; *p<0.05.

Tab. III. Self-assessed overall voice quality in transgender women at three evaluated time points.

VOICE QUALITY	PRE-OPERATIVE (1)		SHORT-TERM FOLLOW-UP (2)		LONG-TERM FOLLOW-UP (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)	p-VALUE (2) *vs* (3)
	n	%	n#	%	N	%			
Poor	3	42.86	0	0.00	2	28.57			
Fair	4	57.14	1	14.29	3	42.86			
Good	0	0.00	3	42.86	2	28.57	**0.043***	0.273	**0.043***
Very good	0	0.00	2	28.57	0	0.00			

*The self-evaluation of voice quality in the V-RQOL questionnaire was not completed by one transfeminine individual (no. 7.) in the short-term follow-up assessment; *p<0.05.

Tab. IV. Correlations between fundamental frequencies and self-assessment of the voice-related quality of life in transgender women during long-term postoperative evaluation.

VARIABLE		r	p-VALUE
Fo (Hz)	VHI – total	–0.68	0.094
	VHI – functional	**–0.82**	**0.023***
	VHI – emotional	**–0.86**	**0.012***
	VHI – physical	0.09	0.848
	V-RQOL score	**–0.85**	**0.016***
	TWVQ score	–0.67	0.102
	VAS score – satisfaction with the procedure's results	0.72	0.068
	VAS score – self-perceived vocal femininity	0.47	0.284
sFo (Hz)	VHI – total	–0.50	0.253
	VHI – functional	–0.14	0.760
	VHI – emotional	–0.31	0.504
	VHI – physical	0.11	0.818
	V-RQOL score	–0.32	0.478
	TWVQ score	–0.58	0.175
	VAS score – satisfaction with the procedure's results	**0.79**	**0.033***
	VAS score – self-perceived vocal femininity	0.71	0.074

SD – standard deviation; Fo – fundamental frequency; sFo – speaking fundamental frequency; VHI – Voice Handicap Index; V-RQOL – Voice-Related Quality of Life; TWVQ – Trans Women Voice Questionnaire; VAS – Visual Analog Scale; r – Spearman's rho correlation coefficient; Hz – Hertz; *p<0.05.

Additional parameters and correlations assessed during long-term follow-up

In the long-term follow-up, the mean overall score in the TWVQ amounted to 52.43 points (SD 17.28). On the 10-cm VAS scale, subjective satisfaction with the procedure's results was rated as 7.29 cm (SD 2.14), while the self-perceived vocal femininity as 6.14 cm (SD 2.12). Furthermore, the mean F0 value showed a significant inverse correlation with the mean score obtained in the functional and emotional domains of VHI-30 (rho = –0.82, p = 0.023, and rho = –0.86, p = 0.012, respectively), as well as with the V-RQOL score (rho = –0.85, p = 0.016). Additionally, the mean sF0 value in the long-term follow-up assessment was positively correlated with subjective satisfaction with the procedure's results evaluated using the VAS scale (rho = 0.79; p = 0.033). Detailed data regarding the correlations between fundamental frequencies and self-assessment of the voice-related QoL are presented in Tab. IV.

Transfeminine individuals *vs.* control groups

Comparison of the acoustic analysis results in transgender women with the control groups of cisgender males and females rendered

Tab. V. Comparison of the acoustic parameters between transgender women in the preoperative assessment and cisgender controls.

PARAMETER	PRE-OPERATIVE (1)		CISGENDER MALES (2)		CISGENDER FEMALES (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)
	MEAN	SD	MEAN	SD	MEAN	SD		
F0 (Hz)	158.35	33.34	119.9	16.17	210.47	16.58	**0.021***	**0.015***
sF0 (Hz)	145.31	28.05	118.99	14.08	227.35	16.27	0.125	**0.002****
F1 (Hz)	683.40	156.82	788.87	65.87	893.17	135.91	0.074	**0.021***
F2 (Hz)	1294.91	143.04	1187.21	93.57	1338.43	110.47	0.160	0.443
F3 (Hz)	2781.07	477.61	2686.33	141.8	2621.53	591.47	0.609	0.701
F4 (Hz)	3764.58	288.74	3569.44	184.72	3908.99	333.01	0.201	0.609
Lower limit of the frequency range of spoken voice (Hz)	90.45	21.96	92.87	16.94	173.67	2.68	0.609	**0.002****
Upper limit of the frequency range of spoken voice (Hz)	280.65	143.52	147.28	22.21	329.45	74.11	**0.021***	0.250
Frequency range of spoken voice (ST)	18.18	9.68	8.03	2.48	10.71	3.95	**0.021***	0.160

SD – standard deviation; F0 – fundamental frequency; sF0 – speaking fundamental frequency; F1 – first formant frequency; F2 – second formant frequency; F3 – third formant frequency; F4 – forth formant frequency; Hz – Hertz; ST – semitones; *p<0.05; **p<0.01.

significant differences at all evaluated time points. During the preoperative assessment, the mean F0 value was significantly higher in the transfeminine individuals compared to the cisgender male controls (p = 0.021) while being substantially lower than in the cisgender females (p = 0.015). The mean sF0 and F1 values in transgender women were significantly lower than in cisgender female individuals (p = 0.002 and p = 0.021, respectively) and did not differ considerably from the values observed in cisgender males. The lower limit of the frequency range of spoken voice was significantly higher in cisgender females than in transfeminine individuals (p = 0.002). Concurrently, the frequency range of spoken voice and its upper limit were significantly higher in transgender women compared to the cisgender male controls (p = 0.021). Detailed data regarding the differences in acoustic parameters' values between cisgender controls and transfeminine individuals in the preoperative period are presented in Tab. V.

During the short-term follow-up assessment (Tab. VI.), the mean F0 values were significantly higher in the transfeminine cohort compared to cisgender male and female controls (p = 0.002). Additionally, the mean sF0 achieved significantly higher values in transfeminine individuals compared to the cisgender males (p = 0.002) and did not differ considerably from the values observed in cisgender females. Notably, the lower and upper limits of the frequency range of spoken voice were significantly higher in transgender women compared to cisgender males (p = 0.007 and p = 0.002, respectively), while being comparable to the values observed in cisgender female controls.

Furthermore, in the long-term postoperative evaluation, the mean F0 and sF0 values, as well as the upper and lower limits of the frequency range of spoken voice in transfeminine individuals remained significantly higher than in cisgender males (p = 0.002), while being comparable to the values observed in cisgender female controls. Similarly, the frequency range of spoken voice achieved significantly higher values in transgender women compared to cisgender males (p = 0.041), while not being considerably different from the values observed in cisgender female controls. Detailed data regarding the differences in acoustic parameters' values between cisgender controls and transfeminine individuals in the long-term follow-up evaluation are presented in Tab. VII.

Additional survey results

In the preoperative period, 2 out of 7 (28.57%) transfeminine individuals (patient no. 5 and no. 7 in Tab. VIII.) attended VT, whereas another 2 out of 7 (28.57%) transgender women (patient no. 1 and no. 2 in Tab. VIII.) reported attending speech training after WG.

One out of seven transgender women (14.29%; patient no. 6 in Tab. VIII.) reported smoking tobacco after WG. None of the patients underwent other pitch elevation procedures since WG. All transfeminine individuals considered their current voice more feminine compared to the preoperative period. Four out of seven patients (57.14%) reported their current voice to be hoarser compared to the preoperative period. Additionally, six out of seven patients (85.71%) considered the strength of their current voice to be lower than before WG.

Regarding patients' difficulties in telephone communication, one out of seven transfeminine individuals (patient no. 1 in Tab. VIII.) reported being sometimes addressed as "Mr." during telephone conversations and sometimes noticing the uncertainty or hesitation of their interlocutors due to the sound of their voice. The remaining transgender women rated the frequency of voice-related difficulties in telephone communication as "never" or "almost never".

Perception telephone test

During the perceptual voice assessment, all speech samples were rated by 64 listeners (27 males and 37 females). Statistical analysis of the listeners' ratings of repeated voice samples rendered low intralistener variability (p>0.05). Tab. VIII. shows individual results for all 7 transfeminine individuals regarding gender attribution during perceptual voice evaluation.

Cisgender female speakers were perceived correctly in 98.66%, whereas cisgender male speakers – in 100% of the cases. The voice samples of transfeminine individuals were assigned to a female gender in 84.38% and to a male gender in 15.63% of all ratings.

Tab. VI. Comparison of the acoustic parameters between transgender women in the short-term follow-up assessment and cisgender controls.

PARAMETER	TRANSGENDER WOMEN (1)		CISGENDER MALES (2)		CISGENDER FEMALES (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)
	MEAN	SD	MEAN	SD	MEAN	SD		
F0 (Hz)	283.41	52.78	119.9	16.17	210.47	16.58	**0.002****	**0.002****
sF0 (Hz)	237.60	34.26	118.99	14.08	227.35	16.27	**0.002****	0.898
F1 (Hz)	567.39	191.78	788.87	65.87	893.17	135.91	**0.030***	**0.015***
F2 (Hz)	1393.13	354.79	1187.21	93.57	1338.43	110.47	**0.041***	0.701
F3 (Hz)	2773.15	449.27	2686.33	141.8	2621.53	591.47	0.701	0.609
F4 (Hz)	3634.94	258.56	3569.44	184.72	3908.99	333.01	0.443	0.097
Lower limit of the frequency range of spoken voice (Hz)	170.39	55.12	92.87	16.94	173.67	2.68	**0.007****	0.523
Upper limit of the frequency range of spoken voice (Hz)	341.62	78.52	147.28	22.21	329.45	74.11	**0.002****	0.798
Frequency range of spoken voice (ST)	12.47	5.87	8.03	2.48	10.71	3.95	0.160	0.609

SD – standard deviation; F0 – fundamental frequency; sF0 – speaking fundamental frequency; F1 – first formant frequency; F2 – second formant frequency; F3 – third formant frequency; F4 – forth formant frequency; Hz – Hertz; ST – semitones; *p<0.05; **p<0.01.

Tab. VII. Comparison of the acoustic parameters between transgender women in the long-term follow-up assessment and cisgender controls.

PARAMETER	TRANSGENDER WOMEN (1)		CISGENDER MALES (2)		CISGENDER FEMALES (3)		p-VALUE (1) *vs* (2)	p-VALUE (1) *vs* (3)
	MEAN	SD	MEAN	SD	MEAN	SD		
F0 (Hz)	235.67	32.85	119.9	16.17	210.47	16.58	**0.002****	0.250
sF0 (Hz)	209.85	26.74	118.99	14.08	227.35	16.27	**0.002****	0.201
F1 (Hz)	820.6	96.18	788.87	65.87	893.17	135.91	0.609	0.371
F2 (Hz)	1375.44	147.96	1187.21	93.57	1338.43	110.47	**0.030***	0.701
F3 (Hz)	2474.58	330.04	2686.33	141.8	2621.53	591.47	0.074	0.609
F4 (Hz)	3851.72	304.88	3569.44	184.72	3908.99	333.01	0.097	0.798
Lower limit of the frequency range of spoken voice (Hz)	159.02	17.14	92.87	16.94	173.67	2.68	**0.002****	0.074
Upper limit of the frequency range of spoken voice (Hz)	319.4	65.24	147.28	22.21	329.45	74.11	**0.002****	0.798
Frequency range of spoken voice (ST)	11.85	2.81	8.03	2.48	10.71	3.95	**0.041***	0.523

SD – standard deviation; F0 – fundamental frequency; sF0 – speaking fundamental frequency; F1 – first formant frequency; F2 – second formant frequency; F3 – third formant frequency; F4 – forth formant frequency; Hz – Hertz; ST – semitones; *p<0.05; **p<0.01.

The gender of transfeminine individuals was significantly more often incorrectly assigned than the gender of cisgender males and females (p<0.001).

Comparison of male and female listeners showed no significant differences in gender perception of transgender patients and cisgender controls. Regarding the individual distribution of the ratings, six out of seven (85.71%) transfeminine individuals were perceived as female in more than 50% of cases. Furthermore, no statistically significant correlations were observed between the percentage of transgender women's voice ratings as a female and the acoustic analysis results during the long-term follow-up visit (Tab. IX.). Similarly, the percentage of ratings as a female was not significantly correlated with the self-assessed vocal femininity and satisfaction with the procedure's results.

Interestingly, the voices of transfeminine individuals were significantly more often perceived as dysphonic (in 66.74% of cases) compared to the voices of cisgender male and female controls (29.91% and 23.66%, respectively) (p<0.001). Nevertheless, no statistically significant correlation was shown between the percentage of the voice ratings as dysphonic and the self-assessed vocal femininity (r = –0.40, p = 0.374), as well as satisfaction with the procedure's results (r = 0.34, p = 0.452).

DISCUSSION

Durability of the acoustic changes induced by Wendler glottoplasty

The durability of acoustic changes induced by various pitch elevation procedures might have an impact on the congruence between the voice and gender perception and, therefore, on the overall satisfaction of transgender women with their voice. Although the mean postoperative follow-up period in two recently conducted meta-analyses (aiming to 15.6 months [21] and 12.5 months [5], respectively) enabled to assess the frequency of postoperative WG complications, it remains insufficient to determine whether the increased pitch tends to persist in the long-term observation. Casado et al. reported a gradual reduction of the initially obtained F0 value in up to 20% of patients undergoing WG, which has been

associated with patients' age over 45 years and smoking tobacco [15]. Moreover, despite an increase in F0 of 45 Hz 6 months after WG compared to the preoperative period, Mora et al. observed a decrease of this difference to 41 Hz 12 months after the procedure, which suggests a tendency to reduce the pitch in the more extended follow-up period [16].

Contrarily, the long-term observation in our study revealed the persistence of the initially increased F0 and sF0 values, as well as the lower limit of the frequency range of the spoken voice, with statistically significant differences compared to the preoperative evaluation after an average follow-up period of 18.63 months. Notably, the mean F0 value in the long-term follow-up evaluation, equaling 235.67 Hz, noticeably exceeded the overlap F0 range from 145 Hz to 165 Hz, above which the given voice can be unequivocally assigned to the female gender. Concurrently, the lack of statistically significant postoperative increase in FFs values in our series was in line with the existing literature [6, 12, 22] and anticipated due to the inability of WG to influence the resonance phenomenon occurring in the supralaryngeal vocal tract, from which the FFs are generated.

Similarly to our findings, in the Anderson et al. study, the increase in F0 values induced by WG remained similar throughout the follow--up period, lasting from 6 to 24 months [23]. Furthermore, Kim et al. showed a gradual increase in F0 values during the 12-month follow-up period, which was attributed to various postoperative changes from the wound-healing process: 1) anterior glottal web contracture and VF tightening, 2) readaptation of the feedback mechanism connecting nerve centers with the executive elements of the articulatory apparatus (including shortened vibratory portions of the VFs), and 3) restoration of the appropriate phonatory pattern [24]. Notably, since numerous authors indicated that the addition of VT might contribute to more remarkable acoustic changes [25] and a faster increase in F0 values after WG [26], it might aid in optimizing the overall results of the voice feminization process [5, 11, 24–32]. Therefore, in order to assess in detail the durability of the acoustic changes induced by WG, further randomized large--cohort studies incorporating both WG and VT and comparing the objective results during a more extended follow-up period are highly warranted to support the idea of the interdisciplinary management of transgender women aimed at a complete voice feminization [5, 15, 25, 30, 31].

Self-assessment of the pitch quality and voice-related quality of life

Despite a significant improvement in the overall VHI-30 score in our cohort at the short-term follow-up, the mean values in the short-term and long-term assessments exceeded 30 points, which is associated with moderate voice-related difficulties and comparable with the results presented by other authors [26, 29, 30, 33]. Nevertheless, a significant postoperative score decrease in the emotional domain of VHI-30, maintained throughout the long-term follow-up period, indicates a persistent positive impact of WG on patients' feelings surrounding their voices. The lack of significant differences in the functional and physical domains of VHI-30 might be partially attributed to the insufficient sensitivity

Tab. VIII. Individual data and results of the perception telephone test for transgender women in the long-term postoperative evaluation.

PATIENT NO.	AGE (YEARS)	INTERVAL SINCE WG (MONTHS)	NO. OF VT SESSIONS		F0 (HZ)	SF0 (HZ)	LOWER LIMIT OF THE FREQUENCY RANGE OF SPOKEN VOICE (HZ)	VAS – SATISFACTION WITH WG RESULTS (CM)	VAS – SELF--ASSESSED VOCAL FEMININITY (CM)	FEMALE VOICE ATTRIBUTION – ALL LISTENERS (%)	FEMALE VOICE ATTRIBUTION – CISGENDER MALE LISTENERS (%)	FEMALE VOICE ATTRIBUTION – CISGENDER FEMALE LISTENERS (%)
			BEFORE WG	AFTER WG								
1	30	20.92	–	5	218.98	191.81	151.86	5	5	73.44	74.07	72.97
2	27	20.66	–	2	221.07	217.31	181.23	7	6	98.44	100.00	97.30
3	53	20	–	–	204.93	233.61	172.29	8	8	100.00	100.00	100.00
4	47	19.95	–	–	267.2	199.85	164.24	8	8	90.63	96.30	86.49
5	20	19.76	24	–	197.61	162.31	127.18	4	2	28.13	29.63	27.03
6	38	17.89	–	–	258.89	232.26	158.12	10	7	100.00	100.00	100.00
7	42	11.23	30	–	281.0	231.8	158.23	9	7	100.00	100.00	100.00

SD – standard deviation; F0 – fundamental frequency; sF0 – speaking fundamental frequency; WG – Wendler glottoplasty; VT – voice therapy; VAS – Visual Analog Scale; Hz – Hertz.

Tab. IX. Correlations between the percentage of female voice attribution, the acoustic analysis results, the self-perceived vocal femininity, and satisfaction with the procedure's results in transgender women during long-term postoperative evaluation.

VARIABLE		r	p-VALUE
Percentage of female voice attribution	F0 (Hz)	–0.41	0.364
	sF0 (Hz)	–0.07	0.875
	F1 (Hz)	0.07	0.875
	F2 (Hz)	–0.04	0.937
	F3 (Hz)	–0.19	0.691
	F4 (Hz)	0.56	0.195
	Lower limit of the frequency range of spoken voice (Hz)	–0.26	0.574
	Upper limit of the frequency range of spoken voice (Hz)	0.11	0.812
	VAS score – satisfaction with the procedure's results	–0.11	0.811
	VAS score – self-perceived vocal femininity	0.30	0.510

F0 – fundamental frequency; sF0 – speaking fundamental frequency; F1 – first formant frequency; F2 – second formant frequency; F3 – third formant frequency; F4 – forth formant frequency; VAS – Visual Analog Scale; Hz – Hertz; r – Spearman's rho correlation coefficient.

of the VHI-30 scale (utilized to evaluate patients with various voice disorders regardless of the underlying pathology) in detecting specific difficulties with voice emission among transgender women. Furthermore, a considerable reduction in the intensity of vocal interference with daily activities was reflected by a significant postoperative decrease in mean V-RQOL score, which, however, showed a negative upward trend in the long-term observation. High subjective satisfaction with the procedure's results in our cohort (7.29 cm on a 10-cm VAS) was comparable to the observations provided by other researchers [5, 7, 16, 28, 29]. Notably, we observed a strong correlation between the subjective satisfaction with WG results and sF0 values obtained during long-term evaluation, which remains in line with Meister et al. findings [7] and highlights the impact of the actual pitch frequency in routine speech on the self-assessed effectiveness of voice feminization procedures.

Similarly to the findings presented in the study by Geneid et al. [33], no significant correlation was observed in our cohort between the improvement in the overall VHI-30 score and the postoperative change in F0. Nevertheless, a significant correlation between F0 values and other voice-related QoL scores (in functional and emotional domains of VHI-30, as well as overall V-RQOL score) in our cohort advocates the necessity of incorporating the subjective patient-reported outcome measures in the evaluation of the voice feminization procedures' effectiveness since the individual perception of everyday vocal functioning might considerably deepen our understanding of the therapeutic success.

Perceptual gender assessment

Contrary to the Meister et al. study [7], in which about 40% of transfeminine speakers were perceived as female by the majority of listeners, in the perception telephone test performed in our cohort, the value of this percentage reached 85.71%. The noticeable discrepancy between the studies' findings could have stemmed from the limited sample size and significantly higher mean F0 value observed in our cohort in the long-term follow-up evaluation (235.67 Hz *vs.* 174 Hz in the Meister et al. study [7]). Furthermore, in contrast to Meister et al. [7] and Coleman et al. [34] findings, we did not observe a significant correlation between the F0 value and the percentage of ratings as a female speaker. Notably, although the mean postoperative F0 value among transfeminine individuals in our study was in the typical female frequency range (> 165 Hz), the elevation of the vocal pitch does not always guarantee being perceived as female [5, 7], which was confirmed by several authors reporting individual voices assigned to the male gender despite the F0 amounting to 170 Hz [35], 180 Hz [36], or even 210 Hz [37]. Regarding our cohort, the voice of patient no. 5 was more frequently associated with the male gender despite the F0 value reaching 197.61 Hz. This observation might be partially attributed to the fact that sF0, reflecting the individual's actual pitch in a conversation, generally yields lower values than F0 and, in the case of patient no. 5, fell into the overlap frequency range, in which unequivocal gender attribution might prove infeasible. Additionally, despite the postoperative increase of the lower limit of the frequency range of spoken voice, patient no. 5 still had access to the frequency range characteristic for the male gender, which might partially explain the low level of their self-assessed vocal femininity and satisfaction with WG results. Therefore, our study indicates that objective acoustic measures – both F0 and sF0, with the latter theoretically representing the transfeminine individuals' pitch in everyday functioning – do not constitute the sole acoustic cues listeners reference to in the given individual's voice attribution to the female gender [38]. These observations indicate that the gender perception is influenced by an array of factors beyond the scope of the present study, such as the visual transmission of gender cues, prosody, resonance, loudness, articulation, and, presumably, a lesser variety of intonational patterns associated with vocalization of a standardized sentence instead of spontaneous speech samples [5, 14, 35, 39]. Nevertheless, due to the limited sample size in studies on perceptual voice assessment of transgender women undergoing WG and the lack of a significant correlation between the perceptual gender evaluation and patient satisfaction with their voice [13], future large-cohort studies including multivariate analysis of both objective and subjective factors would be highly warranted in order to determine the preferred outcome measures affirming the WG success.

Limitations

The limitations of the present study include its retrospective character and small sample size, partially arising from the scarcity of performing the WG procedure in our country. The retrospective nature of the study contributes to the fact that some data collected only during the long-term follow-up (e.g., TWVQ scores) can be utilized solely for comparison with the results of future papers on this topic. Moreover, with the time passing since WG, the transfeminine individuals preferred not to be reminded of the transition process, and only 63.6% of the individuals from our previously assessed cohort [6] could be contacted to request voice sample recording and completion of postoperative questionnaires. A greater number of transgender women would have provided more valid comparisons with cisgender controls, which might have strengthened the generalizations that can be drawn from this study.

The lack of a standardized perioperative VT protocol and the discrepancies among the patients regarding VT attendance precluded the analysis of VT's influence on long-term WG outcomes. Furthermore, the content of the sentence selected for the perceptual telephone test might have had an impact on gender perception. Additionally, the measurement of decision time in the perceptual telephone test might have provided additional information regarding the uncertainty of gender attribution among the listeners.

CONCLUSIONS

With the above limitations taken into consideration, the findings of our study suggest the durability of acoustic changes induced by WG in long-term observation, which renders it an effective method of surgical voice feminization in transgender women. The gradual reduction of the initial improvement in voice-related QoL questionnaires advocates the need for multidisciplinary management of transfeminine individuals to generalize and consolidate the vocal changes acquired through surgical intervention. Nevertheless, the objective acoustic measures cannot guarantee being assigned to the female gender by external evaluators, indicating the beneficial role of perceptual voice assessment in the multidimensional analysis of WG outcomes.

DECLARATIONS

Ethics approval

The Institutional Review Board of the Ethics Committee of Medical University of Silesia in Katowice, Poland, approved the study protocol (No. BNW/NWN/0052/KB/306/24).

Consent to participate

Informed consent was obtained from all participants involved in the study.

Declaration of Generative AI and AI-assisted technologies in the writing process

No generative AI and AI-assisted technologies were used during the preparation of this work.

Availability of data and material

The data generated during this study are available within the article. Datasets analyzed during the current study preparation are available from the corresponding author upon reasonable request.

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