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Original articles

Vocal rehabilitation in singers with vocal complaints: a digital kymography analysis

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ABSTRACT

Purpose: to evaluate the effects of the Comprehensive Vocal Rehabilitation Program associated with the application of transcutaneous electrical nerve stimulation through digital kymography in singers with vocal complaints.

Methods: an experimental intrasubject comparative study in 24 singers, who underwent the rehabilitation program associated with transcutaneous electrical nerve stimulation. They were assessed with laryngeal high-speed videoendoscopy before and after vocal rehabilitation. The paired t-test and Wilcoxon test were used to compare the two assessments. The significance level was set at 5%.

Results: significant differences were found in the maximum opening, dominant amplitude of the opening variation and dominant frequency of the opening variation of the right vocal fold in the posterior glottic region, and in maximum opening, mean opening, dominant amplitude of the opening variation of the left vocal fold and dominant frequency of the opening variation of both vocal folds in the anterior glottic region.

Conclusion: the results showed that the Comprehensive Vocal Rehabilitation Program associated with transcutaneous electrical stimulation decreased the opening amplitude of the vocal fold, increased the vibration frequency, and improved glottal closure in the anterior and posterior glottic regions.

Keywords: Voice; Voice Disorders; Voice Training; Transcutaneous Electric Nerve Stimulation; Laryngoscopy; Kymography

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INTRODUCTION

Observation of laryngeal images and objective assessments of the vocal fold (VF) vibration pattern are essential for accurately diagnosing and indicating the best treatment approach for various voice disorders[1-3].

Laryngeal high-speed videoendoscopy (HSV) is a laryngoscopy examination that acquires a high rate of VF vibration images cycle by cycle[3]. HSV is superior to other laryngeal image observation techniques in that it records and registers the VF movement at speeds several times higher than its vibration frequency and then displays the images at considerably lower rates, making them visible to the naked eye[3].

The literature on HSV indicates that it characterizes laryngeal structures and glottic function in laryngeal assessment as well as or better than videolaryngostroboscopy recordings[1,4,5]. HSV helps assess laryngeal lesions when videolaryngostroboscopy findings are not interpretable[4] or allow for a better diagnosis of some types of dysphonia, such as presbyphonia[5].

One of the characteristics of high-speed technology is that it provides precise material on glottic cycles for quantitative analyses[6]. Derived from HSV, digital kymography (DKG) records successive images of selected horizontal lines in the HSV video to represent the VF vibration movement as a function of time in a single image[7,8]. Hence, DKG enables the effective quantitative study of mucosal wave parameters and vibration through HSV-derived kymograms[9]. By selecting more than one horizontal line, DKG makes it possible to investigate multiple regions of the VF during the glottic cycle[4,6]. Therefore, it also analyzes differences in anteroposterior VF vibration and quantitatively analyzes VF vibration amplitude and frequency[6]. With the possibility of recording the entire VF movement during phonation, DKG is considered the best choice for evaluating the temporal characteristics of HSV data[10]. Given these characteristics, DKG offers information on VF vibration changes closely related to dysphonic voices[6,11].

All patients at vocal clinics have recurrent voice problems, which is also true of occupational voice users[12]. Far more common among these professionals is the negative impact that vocal problems have on their ability to work, their general sense of well-being, and sometimes their identity[12].

Singers stand out among occupational voice users as having one of the greatest vocal demands and vulnerability to dysphonia[13]. Mild and recurrent changes in singers' voice quality can have serious professional and economic consequences[14]. In the context of dysphonia, vocal rehabilitation works to improve the functional voice, with a large part of this effect resulting from the techniques used[15]. Completing vocal rehabilitation can be essential for maintaining and continuing the career of singers who use their voice professionally or recreationally[16].

Various therapeutic techniques and methods are applied to vocal rehabilitation in speech-language-hearing clinical practice with varying degrees of scientific evidence[15,17]. The rehabilitation of voice disorders in Brazil traditionally places a significant emphasis on symptoms and adopts a holistic approach to the use of vocal techniques[18]. However, a well-structured method increases the likelihood of establishing a solid therapeutic relationship and promoting patient adherence, as it previously defines the stages of treatment and the objectives to be achieved[17]. In this regard, the Comprehensive Vocal Rehabilitation Program (CVRP) is a vocal rehabilitation method developed in Brazil with a holistic approach program[10,11]. CVRP provides evidence of improvement in vocal quality, laryngeal function, and quality of life in patients with behavioral dysphonia[19,20].

The range of clinical vocal rehabilitation techniques includes some modern ones, such as electrical currents, which are used to relieve pain, improve circulation, activate cells, improve proprioception, and relax muscles[15]. The currents most used in vocal rehabilitation are transcutaneous electrical nerve stimulation (TENS) and functional electrical stimulation (FES)[15]. The frequency, pulse duration, intensity, and wave shape are the essential parameters in electrotherapy and determine the type of electrical current[15]. The combination of these four parameters defines the type of current, with different effects on the tissues[15]. The literature presents TENS as a noninvasive therapeutic tool that provides analgesia through electrical stimulation on the skin, effectively reducing muscle tension[21,22].

Combining vocal techniques with TENS to reduce muscle tension restores functionality and muscle mobility in the extrinsic region of the larynx, shoulder girdle, and neck, also with suggested positive results in the vocal rehabilitation of dysphonic individuals[21-26]. Although the literature demonstrates positive CVRP[19,20] and TENS[21-26] effects in dysphonia rehabilitation, scarce research has used HSV to analyze the effects of therapeutic procedures on glottal function[27,28]. It is important to understand the functional changes in VF vibration as a result of singers' clinical voice rehabilitation so that therapeutic protocols can be defined according to the functional aspects of these professionals' larynx.

This research hypothesizes that CVRP-based vocal rehabilitation associated with TENS in female singers with vocal complaints have positive effects on the glottal cycle by increasing the VF vibration amplitude and decreasing the glottic space.

Kymograms provide information on changes in the VF vibration behavior resulting from voice therapy and help increase diagnostic accuracy and therapeutic decisions by highlighting parameters related to the glottal cycle[6,11]. This study aimed to assess the effects of CVRP associated with TENS in the vocal rehabilitation of singers with voice complaints, based on DKG parameters.

METHODS

Participants

This experimental intrasubject comparative study was approved by the Research Ethics Committee at the Universidade Federal de Minas Gerais, Brazil, under CAAE number 59014916.6.0000.5149. It is a phase-II study, with a single-subject design with the clinical condition to obtain evidence that the experimental treatment has positive effects on the VF vibration process[29].

The research had a convenience sample based on the following inclusion criteria: being female; aged 18 to 55 years; either a professional or amateur popular music singer; and having vocal complaints. The participants underwent voice rehabilitation with CVRP associated with TENS and were submitted to HSV at the Speech-Language-Hearing Functional Health Observatory of a higher education institution. All participants signed the informed consent form.

A speech-language-hearing pathologist specializing in voice assessed the vocal complaints.

The presence/absence of the singers' self-reported vocal complaints was verified with three questions on vocal self-perception:

1. Do you have any difficulty or discomfort with your singing voice?
2. Do you have any difficulty or discomfort with your speaking voice?
3. Do you think your voice has suffered any changes?

The presence of vocal complaints was defined based on affirmative answers to the three questions.

The exclusion criteria were as follows: reporting vocal rehabilitation during or just before the first assessment; being a smoker; using any type of systemic medication; being pregnant; being in the menstrual or premenstrual period; having a history of neck surgery; being intolerant or contraindicated to the use of TENS[30]; presenting with signs of gastroesophageal reflux, nausea reflex, laryngeal lesions, and airway infection or symptoms of respiratory allergy during HSV assessment.

Initially, 30 dysphonic singers who had undergone vocal rehabilitation with CVRP associated with TENS were selected from the HSV image bank. Of these, 18 (60.0%) were amateur popular music singers – four of them (22.2%) had occupations that intensively used the speaking voice (two actresses and two teachers). The other 12 (40.0%) were paid professional singers, as self-reported.

Six singers were excluded from the sample because some of their HSV videos had low lighting, poor clarity, or corrupted files. The evaluator responsible for the laryngeal image analysis via software was responsible for excluding the videos whose DKG parameters could not be automatically extracted by the program because of the said characteristics.

Thus, 24 amateur and professional singers were selected, with a mean age of 29.25±6.25 years, ranging from 19 to 42 years. They had the following laryngeal characteristics regarding the type of glottal closure[31]: 11 (46%) women had a median-posterior triangular chink, seven (29%) had complete glottal closure, four (17%) had a posterior chink, and two (8%) had an hourglass chink.

Assessment

The participants were assessed twice: prior to the vocal rehabilitation (A1), performed before it began, and after the rehabilitation (A2), performed when the vocal rehabilitation period had finished. The therapy had six weekly sessions, lasting an average of 30 minutes each. The participants were also instructed to do the vocal exercises twice a day at home, as indicated in the CVRP[19].

A speech-language-hearing pathologist specializing in voice with more than 5 years of experience conducted the vocal rehabilitation. Laryngological evaluations were performed by an otorhinolaryngologist with more than 20 years of experience in laryngeal evaluation. HSV images were used for laryngological diagnosis and laryngeal recording in evaluations.

HSV

Each HSV had 2,000 images per second, recorded with a 70° rigid laryngoscope with 300-W xenon light (KayPentax®, Lincoln Park, New Jersey), color HSV system (model 9710), 512 x 512 pixels, and 8-bit RGB. The video recordings lasted a maximum of 7 seconds. All participants were asked to emit the vowels /i/ and /ε/ at their habitual frequency and intensity, maintaining these characteristics throughout the examination. A speech-language-hearing pathologist was present in all recordings to monitor auditory-perceptively the participants' habitual phonation – i.e., they monitored the participants' emissions throughout the examination; when they deviated from the habitual frequency or intensity, the examination was interrupted, and the participant was instructed to repeat the speech task.

After the recordings, the otorhinolaryngologist selected the HSV image sequence with the best luminosity and visualization of the glottic region.

Intervention

Therapeutic interventions occurred weekly and lasted an average of 30 minutes each, using exercises previously established by the CVRP[19]. In each of the six programmed sessions, TENS was applied throughout the session and the CVRP exercises began after 10 minutes of TENS application. Therefore, the CVRP vocal exercises were performed concomitantly with electrical stimulation.

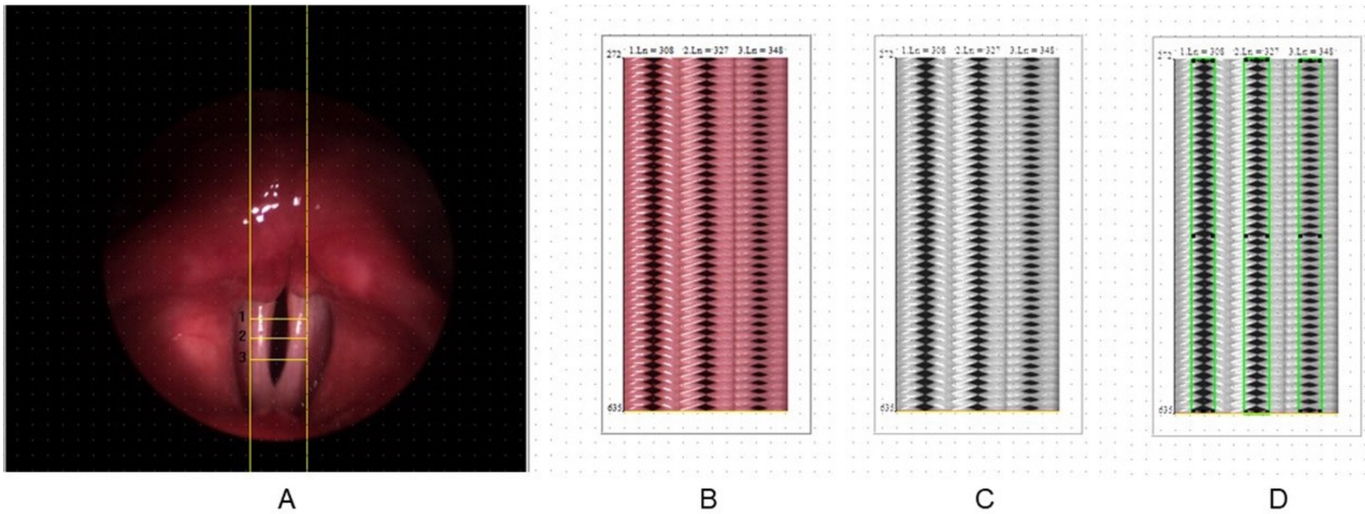
The device used was Neurodyn II® (Ibramed, Amparo, SP, Brazil), model N53, with an adjusted 5-Hz electrical current, 100-microsecond pulse, and intensity regulated according to each participant until muscle contractions were visible, as the threshold for contractions varies within and between subjects. For this procedure, two silicon-carbon electrodes were positioned on the upper trapezius muscle fibers, one electrode on the right muscle and the other on the left muscle.

As established in the CVRP, participants should perform the exercises twice a day at home. In the following session, the therapist asked the participants how often they had done the exercises. Participants did not use TENS at home.

DKG

A single evaluator, using the KIPS® image processing software, version 1.11 (Kay's Image Processing Software, KayPentax), was responsible for analyzing the DKG parameters in each HSV video in the two assessments (A1 and A2).

For the analysis of DKG parameters, the evaluator first delimited by hand the glottic regions, based on which they extracted the kymograms in KIPS®. A pair of vertical lines defined the width of the image, while three horizontal lines divided the posterior, middle, and anterior thirds of the glottis to determine the VF regions to be analyzed. The middle HSV region was selected, excluding the beginning and end of the recording. The program automatically produced a two-dimensional construction of the VF mucosal wave. The evaluator converted the image color mode to grayscale and selected the rima glottidis for each determined line using the edge detection tool (Figure 1). The protocol used to extract DKG parameters follows the instructions in the program manual[32].



Captions: A: Vertical and horizontal lines selected from the laryngeal high-speed videoendoscopy video to extract kymograms. B: Three kymograms automatically generated by the software for each selected horizontal line. C: Color correction for the grayscale. D: Kymograms with automatic screening of the edges of the vocal folds delimited in green.

Figure 1. Digital kymogram extraction scheme

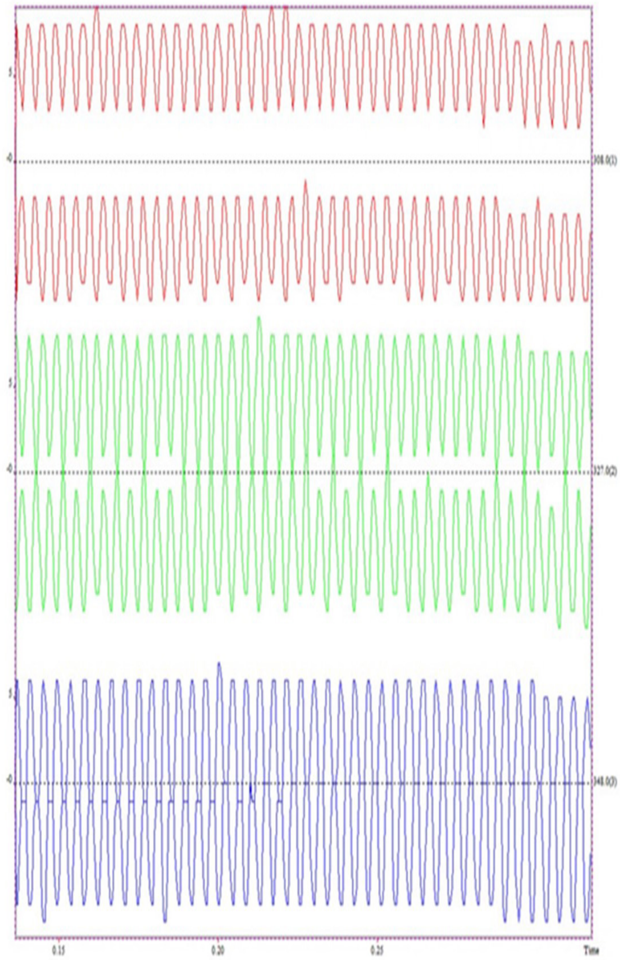
The program automatically generated a tracking graph of the DKG waveform, with the time measured in seconds on the x-axis and the representation of the VF glottal cycle on the y-axis (the left in the upper half and the right in the lower half) (Figure 2). Lastly, the program automatically quantified the results of the DKG analysis considering the parameters indicated in Table 1.

To analyze intrarater agreement, 40% of the DKG examination sample was replicated.

Statistical analysis

Statistical data analysis was performed in the MINITAB statistical software, version 17. First, a descriptive analysis of the data was carried out with measures of central tendency and dispersion. Subsequently, the Anderson-Darling test was used to verify the normality of the sample. The paired t-test or the Wilcoxon test compared DKG measurements between moments A1 and A2. The significance level was set at 5%.

The intraclass correlation coefficient (ICC) was used to determine the intrarater agreement in the measurement of variables analyzed in the PAST© program. The following limits were considered to define the intraclass correlation levels: 0 – 0.5 Poor; 0.5 – 0.75 Moderate; 0.75 – 0.9 Good; and ≥ 0.9 Excellent. The analysis revealed a good to excellent ICC for DKG parameters (Table 2)[33].



Time in the x-axis and vocal folds in the y-axis. In each kymogram, the upper lines represent the opening movement of the left vocal fold, and the lower lines, that of the right vocal fold for each kymogram. The dotted black lines represent the position of reference.

Figure 2. Tracking chart of the waveform in digital kymography

Table 1. List of digital kymography parameters analyzed with Kay's Image Processing Software®

DKG parameter	Concept	Unit of measurement
Minimum opening	Minimum VF opening throughout the glottic cycle in the line selected by kymography, where "0" indicates complete VF closure.	Pixel
Maximum opening	Maximum VF opening throughout the glottic cycle in the line selected by kymography.	Pixel
Mean opening	Mean VF opening throughout the glottic cycle in the line selected by kymography.	Pixel
Dominant amplitude of the opening variation of RVF	Predominant RVF amplitude during the opening in the line selected by kymography.	Pixel
Dominant amplitude of the opening variation of LVF	Predominant LVF amplitude during the opening in the line selected by kymography.	Pixel
Dominant frequency of the opening variation of RVF	Predominant RVF frequency during the opening in the line selected by kymography.	Hertz
Dominant frequency of the opening variation of LVF	Predominant LVF frequency during the opening in the line selected by kymography.	Hertz
Closed quotient	Represents the time proportion of the opening phase of the glottal cycle. It is defined by the opening phase time divided by the total time of the glottal cycle.	Percentage

Captions: DKG: digital kymography, RVF: right vocal fold; LVF: left vocal fold, VF: vocal folds

Table 2. Intraclass correlation coefficient values for intrarater agreement regarding digital kymography parameters

Parameters	ICC
Minimum opening	-*
Maximum opening	0.96
Mean opening	0.82
Dominant amplitude of the opening variation of RVF	0.90
Dominant amplitude of the opening variation of LVF	0.93
Dominant frequency of the opening variation of RVF	0.99
Dominant frequency of the opening variation of LVF	0.99
Closed quotient	0.85

Captions: ICC: intraclass correlation coefficient; *: impossible to calculate; RVF: right vocal fold; LVF: left vocal fold

RESULTS

Significant differences in the posterior region were found between assessments (line 1): decreased maximum opening values (p = 0.053) and dominant amplitude of the opening variation of the right VF (RVF) (p = 0.022); and increased dominant frequency of the opening of RVF (p = 0.054) (Table 3). Significant differences were also found in the anterior region (line 3): decreased maximum opening values (p = 0.050), mean opening (p = 0.036), and dominant amplitude of the opening variation of the left VF (LVF) (p = 0.034); and increased dominant frequency of the opening of RVF (p = 0.018) and dominant frequency of the opening of LVF (p = 0.024) (Table 3).

Table 3. Digital kymography parameters in the posterior (line 1), middle (line 2), and anterior (line 3) glottic region before (A1) and after vocal rehabilitation (A2)

Parameters		Line 1						Line 2						Line 3					
		Mín.	Max.	Mean	SD	Med.	p-value	Mín.	Max.	Mean	SD	Med.	p-value	Mín.	Max.	Mean	SD	Med.	p-value
Minimum opening	A1	0.00	0.00	0.00	0.00	0.00	-*	0.00	0.00	0.00	0.00	0.00	-*	0.00	0.00	0.00	0.00	0.00	-*
	A2	0.00	3.00	0.13	0.61	0.00		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	
Maximum opening	A1	10.00	44.00	20.25	7.44	18.50	0.053	8.00	36.00	16.71	6.05	15.50	0.112#	7.00	30.00	13.58	5.05	12.00	0.050
	A2	9.00	31.00	17.46	5.12	18.50		10.00	25.00	14.50	3.40	14.50		8.00	25.00	11.13	3.47	11.00	
Mean opening	A1	3.72	22.15	9.07	3.79	8.94	0.932	2.32	12.68	5.98	2.23	5.91	0.307#	0.98	10.66	4.49	2.37	3.86	0.036
	A2	3.62	14.55	8.78	2.80	8.25		3.36	9.01	5.48	1.38	5.25		1.51	7.01	3.36	1.45	2.87	
Amplitude of RVF	A1	1.86	11.00	4.31	2.05	4.07	0.022	1.40	6.88	3.46	1.37	3.43	0.237#	0.84	5.73	2.57	1.33	2.19	0.087#
	A2	1.09	5.78	3.42	1.33	3.71		1.85	4.22	3.11	0.73	3.11		1.04	3.61	2.10	0.62	1.97	
Amplitude of LVF	A1	1.66	11.72	4.16	2.08	3.68	0.214	1.12	10.05	3.52	1.77	3.43	0.214	0.65	7.59	2.67	1.64	2.26	0.034
	A2	1.29	5.62	3.32	1.25	3.23		1.89	4.40	2.99	0.69	2.94		0.90	2.91	1.81	0.52	1.74	
Frequency of opening of RVF	A1	125.00	296.88	213.87	37.56	210.94	0.054#	125.00	296.88	213.87	37.56	210.94	0.059#	125.00	296.88	213.54	37.48	210.94	0.018#
	A2	136.72	312.50	231.77	41.37	238.28		136.72	312.50	231.44	40.99	238.28		164.06	312.50	234.70	36.55	238.28	
Frequency of opening of LVF	A1	125.00	296.88	213.87	37.56	210.94	0.058#	125.00	296.88	213.87	37.56	210.94	0.058#	125.00	296.88	214.19	37.57	214.85	0.024#
	A2	136.72	312.50	231.44	41.63	238.28		136.72	312.50	231.44	41.63	238.28		164.06	312.50	234.37	36.88	238.28	
Closed quotient	A1	0.27	66.00	28.42	17.23	24.86	0.074	2.25	64.63	44.06	16.53	45.18	0.466	0.26	73.62	50.44	18.67	54.41	0.679
	A2	0.00	52.74	22.64	17.81	25.64		13.21	60.56	42.23	12.40	45.26		3.91	69.72	51.83	19.47	59.56	

*Impossible to calculate. Captions: #: paired t-test; other ones: Wilcoxon test. p-value < 0.05. Bold: significant p-value; Min.: minimum; Max.: maximum; SD: standard deviation; Med: median. A1: first assessment – before vocal rehabilitation; A2: second assessment – after vocal rehabilitation; RVF: right vocal fold; LVF: left vocal fold.

DISCUSSION

This study investigated the results of applying CVRP associated with TENS on DKG parameters in singers with vocal symptoms and changes in voice quality. Singers make up a specific group of professionals whose income depends almost exclusively on their voices[14,34]. They face great physical and vocal demands to sing with certain voice patterns and intensity for long periods, usually in unsuitable occupational environments[14]. Professional female singers report more health complaints, which can be justified by the association between functional characteristics in women and the high mechanical stress in the mucosa and vocal ligament when singing[14].

The CVRP has positive implications regarding vocal quality, laryngeal image, and self-perception protocols, demonstrating good applicability in cases of behavioral dysphonia[19]. Though scarce, the literature on dysphonia treatment associated with TENS is promising to treat dysphonia, with improved glottal closure and greater phonation comfort and vocal quality when TENS is associated with traditional vocal techniques[24,26].

HSV and DKG analysis provided objective values of glottic behavior before and after vocal rehabilitation. Significant changes were found in DKG parameters concerning maximum opening, dominant amplitude of the opening variation of RVF, and dominant frequency of the opening variation of RVF in the posterior glottic region, as well as in maximum opening, mean opening, dominant amplitude of the opening variation of LVF, and dominant frequency of the opening variation of VF on both sides in the anterior region.

The vibration amplitude depends on the flexibility of the VF tissues, subglottic pressure, and medial compression force, which can increase or decrease the vibration amplitude[35]. Increasing tissue flexibility increases vibration amplitude because flexible tissues are more easily displaced by the force of airflow[35].

The decrease in the dominant amplitude of the opening variation of LVF in the anterior glottic region in the present study corroborates another one that analyzed DKG parameters in nebulization effects, which observed a smaller VF opening amplitude in women with laryngeal changes[28]. The findings demonstrate that VF, after therapeutic intervention, decreases the magnitude of lateral movement during phonation. Possibly, CVRP associated with TENS allows laryngeal readjustment that requires less excursion of the VF mucosa. This finding can be inferred from the fact that the best laryngeal adjustment requires a lower subglottic air pressure and, consequently, a smaller VF opening amplitude.

A study used the CVRP in the treatment of teachers with behavioral dysphonia and found an increase in fundamental frequency (F0) after the speech therapy[20].

Another one assessed voice tongue trill performance and likewise found increased F0[36]. Yet another study associated the tongue trill technique with TENS and found increased F0 values 3 to 5 minutes after completing the technique[37]. VF vibration frequency is determined by its length, tension, and mass; F0 is also determined by these characteristics[38]. Thus, the present study corroborates the increased F0 in the treatment of cases of behavioral dysphonia in the literature[20,36,37].

It is important to highlight that 46% of the women participating in this study had a mid-posterior triangular gap. The glottal gap is a laryngeal sign resulting from several etiological factors, most commonly changes in the free edge of the VF[31]. The greater presence of incomplete glottal closure in the sample may also indicate a greater presence of phase asymmetry of the glottal cycle in the singers. This hypothesis may justify why only one of the VFs had significant results in vibration amplitude and frequency parameters in the posterior region in the DKG analysis.

The anterior glottic region had a greater presence of significant differences in DKG parameters. The VF oscillate in phase, from the lateral to medial plane and from the anterior to posterior plane[31], and the anterior two-thirds of the rima glottidis are occupied by the membranous portion of the VF, representing approximately 52% of the rima glottidis[31,35]. A hypothesis can be raised regarding this finding, based on the anatomy of the VF and the pattern of the glottic cycle. These characteristics suggest that the changes triggered by vocal rehabilitation have a greater effect in this region than in other ones.

It is worth mentioning that the therapeutic period of the research was based on the CVRP, which has five pillars: body-voice, glottal source, resonance, breathing and speech coordination, and communicative attitude. This program considers body-voice integration as essential in people with dysphonia[17,18]. The literature reports that TENS promotes positive physiological changes when associated with conventional techniques in speech-language-hearing clinical practice[23,24]. However, the results of the present study must be interpreted very cautiously. They provide insufficient evidence to affirm that the differences found are associated with TENS, since, as mentioned, the CVRP already indicates positive results regarding aspects related to vocal quality and glottic function. Comparing only glottic function characteristics before and after treatment may result in an evaluation error by not considering other parameters related to vocal production, such as differences in subglottic pressure, airflow, and neck muscle tension.

This study has some limitations, including those related to HSV recording. The literature suggests that recordings below 4,000 frames per second may not be sufficient to record the real VF vibration characteristics[39]. Spatial resolution also influences objective parameters extracted from HSV, and cameras with higher resolution are therefore suggested[40]. These characteristics may lead to inaccurate data on DKG parameters. Another limitation is related to evaluation. Voice production is a multidimensional phenomenon that involves physiological, biomechanical, and aerodynamic mechanisms. However, this research evaluated only one of its dimensions. Furthermore, the few participants in this study are a limitation to the external validity of the results.

CONCLUSION

Among the parameters assessed with DKG, there was a decrease in maximum opening and RVF opening amplitude; an increase in RVF frequency in the posterior glottic region; a decrease in maximum opening, mean opening, LVF opening amplitude; and an increase in frequency in both VF in the anterior glottic region between assessments before and after vocal rehabilitation with CVRP associated with TENS.

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