Reinke's Edema: New Insights into Voice Analysis, a Retrospective Study

Lucia Longo, Lucia Libera Pipitone, Armando Cilfone, Luca Gobbi, and Laura Mariani, *Rome, Italy*

Summary: Purpose. Reinke's edema (RE) is a pathological condition involving increased volume of the vocal folds and resulting in significant impact on speech, fundamental frequency, and vocal range. Literature reports few studies which analyze vocal features according to the severity of RE. The aims of this study were to investigate the aerodynamics, acoustic characteristics, and sound spectrograms of a group of RE patients and to assess whether there was any correlation with their endoscopic grading.

Methods. A total of 98 patients were included in the study, 49 patients with RE and 49 healthy volunteers (HV). Multidimensional Voice Program was used to perform objective voice assessment. Maximum phonation time (MPT) and Voice Handicap Index (VHI) questionnaire were collected. The spectrograms of the vowel /a/ and of the word /aiuole/, which contains the five Italian vowels, of each patient were analyzed according to the classification of Yanaghiara modified by Ricci Maccarini and De Colle. Laryngological assessment was used to record vocal folds morphology according to Yonekawa's classification. Univariate analysis was used to compare group outcomes. Bivariate analysis was used to compare endoscopic grading and voice analysis results.

Results. Univariate analysis of the HV and RE groups revealed statistically significant differences ($P < 0.05$) for the following parameters: jitter%, shimmer%, harmonic-to-noise ratio (NHR), voice turbulence index (VTI), MPT, VHI except for soft phonation index. Spearman's rank correlation showed a positive correlation between vocal parameters such as jitter%, shimmer%, NHR, VTI, and RE gradings. A negative correlation was found between MPT and RE gradings. Bivariate analysis indicated a strong positive correlation between RE grading and the spectrogram classification performed both with the vowel / a / (Rho 0.86; $P = 0.0001$) and with the word / aiuole / (Rho 0.81; $P = 0.0001$).

Conclusion. The present study demonstrates that patients with RE have different voice characteristics compared to HV. In particular, the voice analysis highlighted acoustic parameters that correlated to differing degrees of RE. In addition, spectrogram analysis should be considered for acoustic assessments before and after medical and surgical therapy and also in forensic medicine.

Key Words: Reinke's edema–Voice quality–Voice analysis–Dysphonia–Vocal folds.

INTRODUCTION

Reinke's space is located between the superficial lamina propria and the vocal ligament and is fundamental to the creation of mucosal vibration.[1] In fact, histologically the vocal folds have characteristics related to their phonatory function.[2] Reinke's edema (RE) is a pathological condition associated with various changes in the vocal fold profile[3]; the increase in the volume of the vocal folds is often bilateral and asymmetrical[4] and the main symptom is represented by dysphonia, while a later symptom is dyspnea.[3] Several environmental factors have been hypothesized as being involved in the pathogenesis of RE; however, only smoking appears to have a unique association with the onset of the disease.[5] On the other hand, laryngopharyngeal reflux (LPR) and voice abuse also seem to synergistically predispose some people to the disease, but not independent of smoking.[4] The prevalence in the general population is slightly less than 1% and the disease is more frequent in females around the age of 50.[6] Female patients generally have an earlier diagnosis due to the reduction in the fundamental frequency (F0) generated in a female voice, whereas in male patients the most common manifestation is a lower pitched voice.[3] In fact, it has been shown in some studies that female patients with RE are more often misidentified as male, using only vocal auscultation.[7,8] RE has a significant impact on speech function with F0 and vocal range being greatly reduced. The whole vocal range is affected, but higher ones in particular show a reduction in vocal range, on average, by 17 semitones.[9,10] Zeitels et al showed that, in patients with RE, the mean F0 in females was < 130 Hz and in males it was < 100 Hz[11] compared with an average of 180–230 Hz and 115–160 Hz, respectively. Later on, Lim et al[12] compared the aerodynamic, acoustic, and electroglottographic parameters for the different types of RE using Yonekawa's classification showing that F0, mean flow rate (MFR), degree of closure of the true vocal folds, and maximum phonation time (MPT) differed significantly between varying degrees of RE. In addition, statistically significant differences were found in jitter (jitt%), shimmer (shimm%), and harmonic-to-,noise ratio (NHR) parameters that appear to be suitable measures of objective voice quality. Moreover, Szkiełkowska et al[13] identified a reduction in Open

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From the Department of Sense Organs, Sapienza University, Rome, Italy.

Address correspondence and reprint requests to Lucia Libera Pipitone, Department of Sense Organs, Sapienza University, Viale dell'Università 31, 00161 Rome, Italy. E-mail: lucialibera.pipitone@uniroma1.it

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Quotients (OQ) and an increase in Closed Quotients (CQ) in vocal fold vibratory cycles using Videostrobokymography in RE patients. The correlation between the stage of RE, applying the Yonekawa classification, and the mean values of OQ and CQ was 70%.

Regarding the treatment of RE, the primary medical approach involves the elimination of environmental risk factors. Smoking cessation, voice therapy, and treatment of LPR allow most patients to inhibit the progression of the disease, although no cases of regression have been described.[14] In cases which progress, medical therapy is based on the use of medication with anti-edema action, mainly steroid injection.[15] The next level of treatment is typically surgery using the microflap technique, a surgical option that allows dysphonia improvement without, however, reaching a normalization of the vocal profile.[10] Nevertheless, studies on postoperative outcomes in RE patients have demonstrated an increase in F0 and an improvement in MFR, shimmer, and NHR. Furthermore, the correlation analysis showed that jitter, NHR, average CQ of the vocal folds, and the irregularity of F0 were the parameters best associated with improvements in postoperative voice quality.[12,16]

Although few studies have analyzed vocal parameters in RE patients and their correlation with edema grading, understanding and increasing our knowledge regarding this specific research field may be important for clinicians who deal with this specific population. In fact, providing evidence and data on the clear effect of edema severity on vocal parameters could be particularly useful when objectively evaluating and quantifying vocal improvement and, therefore, the potential benefits of medical or surgical therapy.

Based on these premises, the primary aim of our study was to analyze the aerodynamic and acoustic characteristics of a group of RE patients and compare them with a healthy control group. The secondary aim was to assess whether there was a correlation between endoscopic grading and the subjective evaluation of speech perception and objective acoustic analysis of voice. The tertiary aim was to evaluate the degree of correlation between the sound spectrogram and endoscopic grading.

MATERIALS AND METHODS

Study design and sample

An observational retrospective study on a cohort of 98 patients, with an assessment period from 2019 to 2021 at the Phoniatric Unit of the Department of Sense Organs of Policlinico Universitario Umberto I, Rome. The study population included 49 healthy volunteers (HV) (19 M, 30 F; mean age 28.1 ± 6.7) to assess normal vocal parameters and 49 patients with laryngological diagnosis of RE (5 M, 44 F; mean age 54.9 ± 12.9).

Inclusion criteria of the HV group were as follows: no pathologies of the larynx or vocal tract, no previous head and neck surgery, no smokers, no pathologies that could alter vocal parameters (eg, lung pathology, neurodegenerative, or neuromuscular diseases).

Inclusion criteria for the RE group were as follows: no previous head and neck surgery, no other benign or malignant pathologies of the true vocal folds, no unilateral or bilateral fold paralysis, no lung pathology, neurodegenerative, psychiatric, or immunosuppressive diseases, and no chronic use of steroids or Non-steroidal anti-inflammatory drugs.

Regarding the RE group, their complete medical history and in particular smoking habits and number of cigarettes per day, history of gastroesophageal reflux disease (GERD), body mass index (BMI), family history of vocal fold disease, history of hypothyroidism, and professional use of the voice were collated. Voice analysis and laryngological evaluation were carried out in one single session for both groups.

The study was conducted according to the regulations of the Ethical Committee for retrospective studies of the involved institutions. Informed consent was obtained from all participants. Protocol studies were approved by Institutional Review Board and were conducted according to the principles and rules laid down in the Declaration of Helsinki and its subsequent amendments.

Voice analysis

Multidimensional Voice Program (Model 5105, Version 3.1.4 ©2000–2006 KayPENTAX) was used performing objective voice evaluation. Each voice was recorded with a Shure microphone (SM48 model) positioned at a 45° angle approximately 15 cm from the mouth and slightly below the chin; the environmental noise was 30 dB SPL. Patients were asked to sustain the vowel /a/ at a comfortable loudness level for at least 5 seconds. This sound was recorded with a sampling rate of 50,000 Hz for multi-dimensional voice program analysis. We selected an interval of 3 seconds from the mid portion of the recording to evaluate the following parameters: jitt%, shimm%, NHR, soft phonation index (SPI), voice turbulence index (VTI), and F0. The MPT was determined by holding the vowel /a/ as long as possible on a single breath in a standing position. Longer phonation on three attempts was used. Three classes of severity can be identified for the values below the threshold value: normal value > 10 seconds; mild alteration 8–10 seconds; moderate alteration 5–7 seconds; severe alteration < 5 seconds. Each patient completed dysphonia severity self-assessment through the Voice Handicap Index (VHI) questionnaire Italian translation.[17] The VHI consists of 30 questions regarding the impact of vocal problems on daily activities, the psychological impact, and the perception of the characteristics of the vocal emission. There are three scores: 0–30 (minimal discomfort), 31–60 (moderate discomfort), and 61–120 (significant or extreme discomfort). Spectroacoustic assessment of the voice by spectrograms was used as a semi-objective investigation to evaluate, in RE patients, the harmonic structure of a voice sample using the vowel /a/ and the word /aiuole/, which contains the five Italian vowels. MultiSpeech 3700 CSL 4500 (Model 5105, Version 3.1.4 ©2000–2006 KayPENTAX) was used for spectrogram analysis.

TABLE 1.
Spectrographic Classification (Yanagihara Modified by Ricci Maccarini and De Colle) and Endoscopic Classification (Yonekawa)

Spectrographic Classification of Dysphonia According to Yanagihara Modified by Ricci Maccarini and De Colle	Endoscopic Classification of Reinke's Edema According to the Yonekawa Scale
Class 0. in the standard - absence of noise in the spectrum or presence of noise components that do not predominate over the harmonic components	**Type I.** Edematous swelling is observed on the upper surface of the vocal folds, while patency of the glottis is adequately preserved
Class I. mild alteration - presence of noise components, which above 2000 Hz predominate over harmonic components; harmonics are still present even above 2000 Hz	**Type II.** Edematous swelling extends from the upper to the lower surface beyond the margins of both vocal folds, which are partly in contact with each other
Class II. moderate alteration - presence of noise in the spectrum; harmonics are present only up to 2000 Hz	**Type III.** Edematous swelling is further advanced so that an opening can be seen only at the posterior portion of the glottis, or the swelling is so bulged in a sack-like shape that it hangs down to the subglottic space during inspiration
Class III. high alteration - presence of noise in the spectrum; harmonics are present only up to 500 Hz	
d. diplophony - presence of sub-harmonics	
t. vocal tremor - presence of undulations of the F0	

Considering the spectral distribution of the noise (aperiodic component) and the modifications of the harmonics, Yanagihara proposed a spectrographic classification system of dysphonia still used today as the gold standard.[18] Yanagihara's classification examines the five vowels. To simplify the procedure, Ricci Maccarini-De Colle have proposed an alternative classification. Four types of classification are described, to which the letter "d" is added if diplophony is present and "t" if vocal tremor is present.[19] In our study the spectrograms of the vowel /a/ and of the word /aiuole/ of each patient were analyzed according to the classification of Yanaghiara modified by Ricci Maccarini and De Colle in four classes[20] (Table 1).

Laryngological evaluation and Reinke's edema grading

Video-strobo laryngoscopic evaluation was performed by an ENT laryngologist using a rigid 70° (Hopkins, 8700 CKA, Karl Storz, Germany) laryngoscope and a video endoscopy camera (MediCam Plus LT, Inventis) connected to a laptop (third generation IntelR Quad Core i7).

Laryngological assessment was used to record vocal folds morphology and motility producing an /e/ and an /i/ sound during the examination. All recordings of the RE group were examined by two expert laryngologists giving a score according to Yonekawa's classification[21] (Table 1).

Statistical analysis

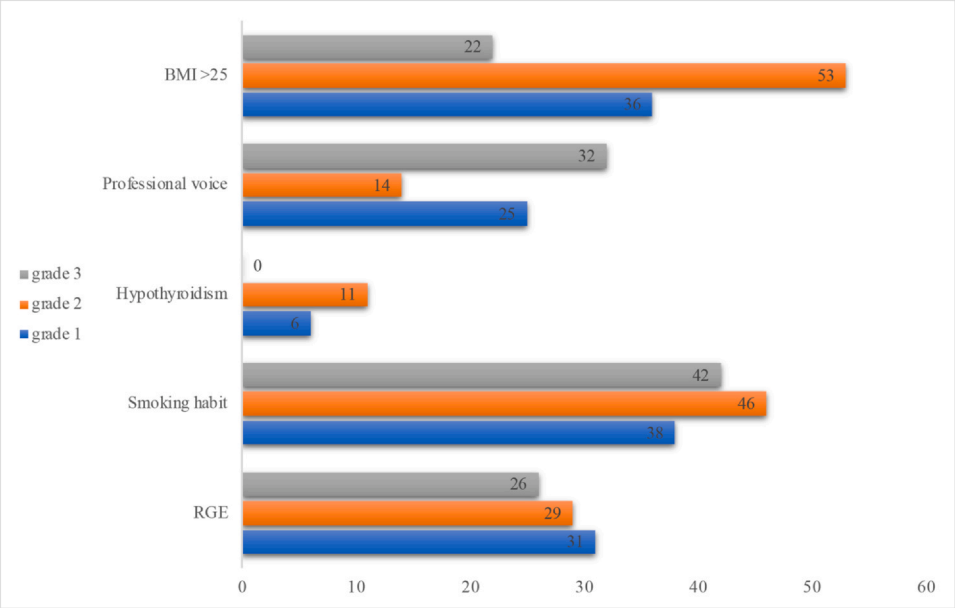
The Shapiro–Wilk test was used to assess normal data distribution. Categorical variables were calculated using frequencies and proportions while continuous data were estimated by means, standard deviations, and ranges.

The inter-rater agreement of the evaluation of RE grading and of spectrogram classification was determined by calculating Cohen's Kappa value. Univariate analysis (*t* test) was used to analyze the differences between the RE group and HV group values in order to establish whether they were significantly different in statistical terms. A P value of less than 0.05 was considered as statistically significant. Simple Spearman's rank order correlation was performed to understand the relationship between objective and subjective voice parameters and Yonekawa grading, and between objective and subjective voice parameters and VHI scores. Simple Spearman's rank order correlation was also used to understand the relationship between spectrogram classification and Yonekawa grading. Statistical analysis was performed using *The Statistical Package for Social Sciences (SPSS)* ver. 25 (SPSS IBM).

RESULTS

Descriptive analysis: RE patients and HV

The Cohen's Kappa value for inter-rater reliability (two independent observers) for laryngological evaluation of RE grading was 0.97. At the laryngeal evaluation, no HV participants showed any functional or organic lesions of the vocal folds. Regarding the RE population, laryngeal assessment diagnosed 25 patients with grade 1, 15 with grade 2, and 9 with grade 3 according to the Yonekawa classification. Among the RE population, 8 patients (16.3%) had a family history of laryngeal pathologies, 24 patients (49%) used their voice professionally, 30 patients (61%) suffered from GERD, 6 patients (12.2%) had hypothyroidism, 20 patients (41%) had BMI >25, and 44 patients (90%) were smokers. Figure 1 shows the distribution of risk factors expressed as a percentage according to the various stages of RE and Figure 2 shows, for smokers, the daily number of cigarettes, and finally the percentage of patients divided by RE stages. All the mean values and standard deviations of the HV group and RE group are reported in Table 2. Univariate analysis between groups including both males and females revealed statistically significant differences ($P < 0.05$) for the following parameters: jitt%, shimm%, NHR, VTI, MPT, and VHI except for SPI. Univariate analysis including only females revealed



BMI: Body mass index
RGE: Gastroesophageal reflux disease

FIGURE 1. Distribution of risk factors for RE according to Yonekawa classification stages.

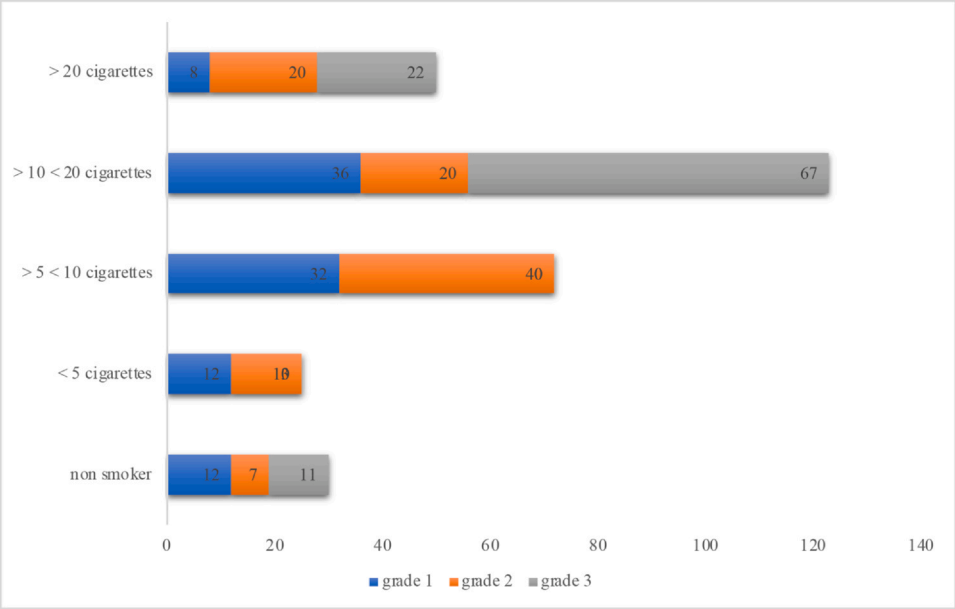


FIGURE 2. Distribution of daily number of cigarettes according to Yonekawa classification stages.

statistically significant differences ($P < 0.05$) for all of the parameters studied, whereas the analysis of the sample of males alone revealed significant differences ($P < 0.05$) for jitt %, shimm%, NHR, MPT, and VHI except for SPI and VTI.

Endoscopic Yonekawa's grading and subjective/objective voice analysis

In RE patients, Spearman's rank correlation showed a positive correlation between vocal parameters such as jitt%, shimm%, NHR, VTI, and Yonekawa grading; these parameters increase linearly with grading. A negative correlation was found between MPT and Yonekawa grading; this score decreases as the grading increases. Finally, a positive correlation between shimm% and VHI score and a negative correlation between MPT and VHI score was found. All the *P* value and Rho outcomes are reported in Tables 3 and 4.

Endoscopic Yonekawa's grading and acoustic analysis

The Cohen's Kappa value for inter-rater reliability (undertaken by two independent observers) for spectrogram classification was 0.92. Bivariate analysis indicates a strong

TABLE 2.
Comparison Between HV Group and RE Group Voice Parameters

	Mean (SD)	Mean (SD)	*P* Value*
Females	*HV group N. 30*	*RE group N. 44*	
Jitter %	0.459 (0.173)	1.322 (0.846)	**0.0001**
Shimmer %	3.076 (1.287)	7.099 (4.392)	**0.0001**
SPI	4.13 (1.84)	6.04 (3.04)	**0.0030**
NHR	0.125 (0.011)	0.187 (0.074)	**0.0001**
VTI	0.060 (0.017)	0.085 (0.043)	**0.0040**
MPT	17.05 (4.74)	11.35 (4.75)	**0.0001**
VHI	10.97 (11.51)	31.82 (24.08)	**0.0001**
F0 Hz	185.846 (7.9)	154.672 (8.4)	**0.0001**
Males	*HV group N. 19*	*RE group N. 5*	
Jitter%	0.386 (0.185)	1.867 (1.873)	**0.0016**
Shimmer %	2.783 (1.159)	9.822 (5.146)	**0.0001**
SPI	7.11 (5.82)	6.37 (2.04)	0.7841
NHR	0.136 (0.016)	0.216 (0.102)	**0.0023**
VTI	0.061 (0.016)	0.073 (0.011)	0.1202
MPT	20.08 (6.61)	10.52 (3.29)	**0.0053**
VHI	12.63 (6.45)	33.40 (10.60)	**0.0001**
F0 Hz	135.969 (8.6)	87.923 (6.3)	**0.0001**
Full sample	*HV group N. 49*	*RE group N. 49*	
Jitter %	0.430 (0.179)	1.397 (0.968)	**0.0001**
Shimmer %	2.962 (1.235)	7.376 (4.492)	**0.0001**
SPI	5.28 (4.10)	6.07 (2.93)	0.2766
NHR	0.129 (0.014)	0.189 (0.076)	**0.0001**
VTI	0.060 (0.016)	0.085 (0.042)	**0.0002**
MPT	18.22 (5.67)	11.26 (4.60)	**0.0001**
VHI	11.61 (9.81)	25.82 (11.17)	**0.0001**

Notes: Significant differences are higlighted in bold.
Abbreviations: HV, healthy volunteers; RE, Reinke's edema; SPI, soft phonation index; NHR, noise-to-harmonic ratio; VTI, voice turbulence index; MPT, maximum phonation time; VHI, voice handicap index; Hz, Hertz; SD, standard deviation.
* *t* test.

positive correlation between Yonekawa grading and the spectrogram classification performed both with the vowel / a / (Rho 0.86; $P = 0.0001$) and with the word /aiuole/ (Rho 0.81; $P = 0.0001$). In RE patients, the spectrograms of the vowel /a/ were 22 of class 0 (45%), 18 of class I (37%), and 9 of class II (18%). Concerning the spectrograms of the word /aiuole/ 24 were of class 0 (49%), 16 of class I (33%), and 9 of class II (18%). Figures 3 and 4 show an example of a spectrogram of vocal /a/ and of the word /aiuole/, respectively, for a patient with class 0 and one with class II, patients who corresponded endoscopically to a grade I and a grade III, respectively.

DISCUSSION

The main aim of this work was to evaluate the aerodynamic and acoustic characteristics of a group of RE patients compared to a healthy control group. Our data showed that RE patients have very different vocal characteristics compared to the healthy population, which shows how pathology has an important impact on the voice.

Several articles describe the hoarse voice in Reinke's edema, due to the thickening of the vocal folds as in polypoid degeneration, which is the cause of a loss of voice pitch control.[4,14,22–24] The main reason through which these lesions affect the voice is the disruption of the vibratory function of the mucosa.[25] Regarding the analysis of the objective vocal parameters, these may reflect their clinical status (as previously highlighted) and in particular the values of jitt% and shimm% which were significantly correlated with RE classification.[12,26] Perturbation parameters such as jitt% and shimm% express the periodicity of the vocal signal; therefore, lower values correspond to a thinner voice.[27] Our findings are in line with previous studies,[28,29] and in fact jitt% and shimm%, which are indicators of glottal vibration irregularity and are perceptually related to breathy and hoarse voices, were significantly increased in patients with RE compared to the HV population. Furthermore, in agreement with Szkiełkowska et al[13] who had found in a cohort of 45 RE patients an NHR value of 0.2, in our study the NHR value increased in RE patients (0.189). Other studies reported a range from 0.25 to 2.9.[14,24,30] NHR value expresses the average ratio between noise/harmonics and constitutes a global assessment of the presence of noise in the medium-low frequency range. In RE patients, the noise component is greater due to the loss of contact between the vocal folds and the increase in vibration irregularity.[12] On the contrary, the NHR parameter is high in healthy voices, because the harmonics predominate over the noise signals.[27,31] In our study, we found that the mean VTI value increased in RE patients (0.085%), and consistently

TABLE 3.
Spearman's Rho and *P* Values Between Yonekawa Grading and Subjective/Objective Voice Parameters. Significant correlations in bold.

	Jitter %	Shimmer %	SPI	NHR	VTI	MPT sec	VHI
	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)
Yonekawa grading	0.5 (**0.0001**)	0.4 (**0.002**)	0.1 (0.374)	0.4 (**0.002**)	0.3 (**0.011**)	−0.31(**0.027**)	0.21 (0.14)

Notes: Significant correlations highlighted in bold.
Abbreviations: SPI, soft phonation index; NHR, noise-to-harmonic ratio; VTI, voice turbulence index; MPT, maximum phonation time; VHI, voice handicap index; sec, second.

TABLE 4.
Spearman's Rho and *P* Values Between VHI Scores and Subjective/Objective Voice Parameters. Significant correlations in bold.

	Jitter %	Shimmer %	SPI	NHR	VTI	MPT sec
	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)	Rho (*P*)
VHI score	0.2 (0.870)	0.3 (**0.032**)	0.2 (0.158)	0.09 (0.506)	0.12 (0.382)	−0.36 (**0.010**)

Notes: Significant correlations highlighted in bold.
Abbreviations: SPI, soft phonation index; NHR, noise-to-harmonic ratio; VTI, voice turbulence index; MPT, maximum phonation time; VHI, voice handicap index; sec, seconds.

high-frequency noise is correlated to turbulence due to incomplete glottal closure and is an acoustic correlate of the breathy voice. Analysis of the male group alone revealed no statistically significant differences, but this could be due to the effect of it being a very small study sample. It would be useful to analyze a larger sample of males to evaluate the effects of RE on this value. The SPI value reflects the force of adduction in the vocal folds. High values of SPI are shown to correlate with incomplete vocal fold adduction and are an indicator of breathiness voice.[32] Our results show no significant difference in SPI values between RE patients and HV, although RE patients demonstrated a mean value higher than HV. It could be hypothesized that patients with RE do not significantly lose their adductor strength due to the mass-effect of the vocal folds and in fact in this type of patient it is easier to have a hoarse voice rather than a breathy voice although this result may be due to the effect of small sample size. As can be seen from the results, this value is statistically significant for females where we have collated a larger sample, compared to males, where we only have a smaller sample. Studies with a larger cohort of males are needed in order to highlight whether the value can be considered useful for the differentiation of patients with RE.

Most of the studies, regarding acoustic analysis, reported only the changes in the F0 parameter. F0 is the most easily objectifiable parameter but at the same time by itself offers little specificity. In females, the mean value of F0 is in the range of 180–230 Hz, in males in the range of 115–160 Hz and in children in the range of 255–440 Hz.[11]

Consistent with previous findings, in our study the RE cohort for F0 in females was 154.67 and 87.92 Hz in males, with statistically significant differences to the HV group. Regarding the F0 value, other studies reported a range from 182.09 to 147.56 Hz for females and a range from 126.63 to 101.06 Hz for males.[27,33]

Moreover, in our study the MPT value for RE patients was significantly lower when compared to the HV participants. This finding could be explained because of the volume of air available for maximum sustained phonation and varies in proportion to the amount of vital capacity and respiratory function[18] and that the patients affected by RE in our study are smokers in 90% of cases, negatively affecting the MPT value. Interestingly, the Lim et al study showed that MPT values decreased according to RE grading, however no clear explanation for this data have been hypothesized.[12]

Regarding the subjective perception of voice evaluated through the VHI test, we found a significantly inferior mean score in RE patients (28.82 points) compared to HV (11.61 points). These findings were similar to the study conducted by Grigaliute et al (mean value 21.45 in RE patients).[27] Other studies focusing on RE population reported VHI scores in a range from 14.86 ± 5.84 points to 56 ± 26 points; however, none of these studies report data from a control group.[16,29,34]

Although the analysis of risk factors associated with RE was not one of the main aims of this study, it is worth reporting that no clear relationship between RE grading and RE associated risk factors was found. Figure 1 demonstrates that the distribution of risk factors based on RE grading was highly variable. In agreement with Goswami et al,[4] we hypothesized that some factors such as GERD, BMI, and vocal abuse would seem to predispose some patients to higher RE degrees in synergy with cigarette smoking but not independently of it. Furthermore, we have not found an effective relationship between the number of cigarettes smoked and endoscopic grading (Figure 2). In our opinion, the risk factors examined are likely to be involved in the chemical-physical assault on the vocal folds, but other genetic-environmental factors, as previously highlighted by other studies,[35,36] should be studied to fully understand the etiology of this pathology.

The secondary aim of this study was to assess any correlations between the endoscopic grading and the subjective evaluation of speech perception and an objective acoustic analysis of voice. Our study showed a reliable correlation between voice features and RE grading. To our knowledge, only a few studies have analyzed specific correlation between RE grading and voice parameters.[12,33] In our study, we found similar results to the study by Lim et al where the results for MPT, NHR, jitt%, and shimm% differed significantly between the different grades of RE.[12] Furthermore, our results also demonstrate a statistically significant difference for the VTI value. The study by Colizza et al demonstrated a correlation between jitt%, shimm %, NHR, F0, and RE gradings; however, it was conducted using another method of RE classification.[33]

Finally, our study evaluated the degree of correlation between the sound spectrogram and endoscopic grading. Our findings revealed a strong positive correlation between RE

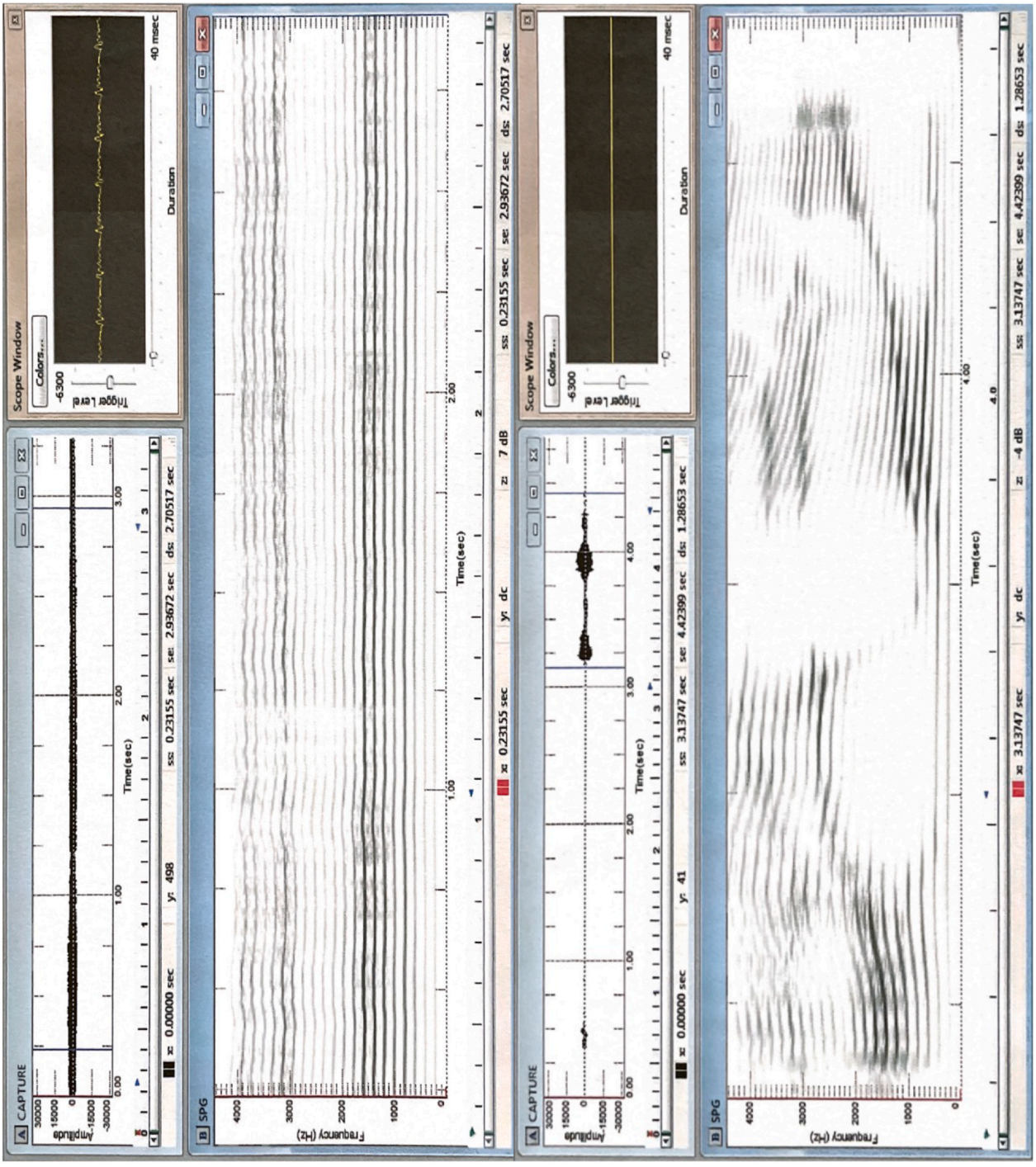


FIGURE 3. Spectrogram of vocal /a/ and word /aiuole/. Class 0 according to the classification of Yanaghiara modified by Ricci Maccarini and De Colle in a patient with RE grade I.

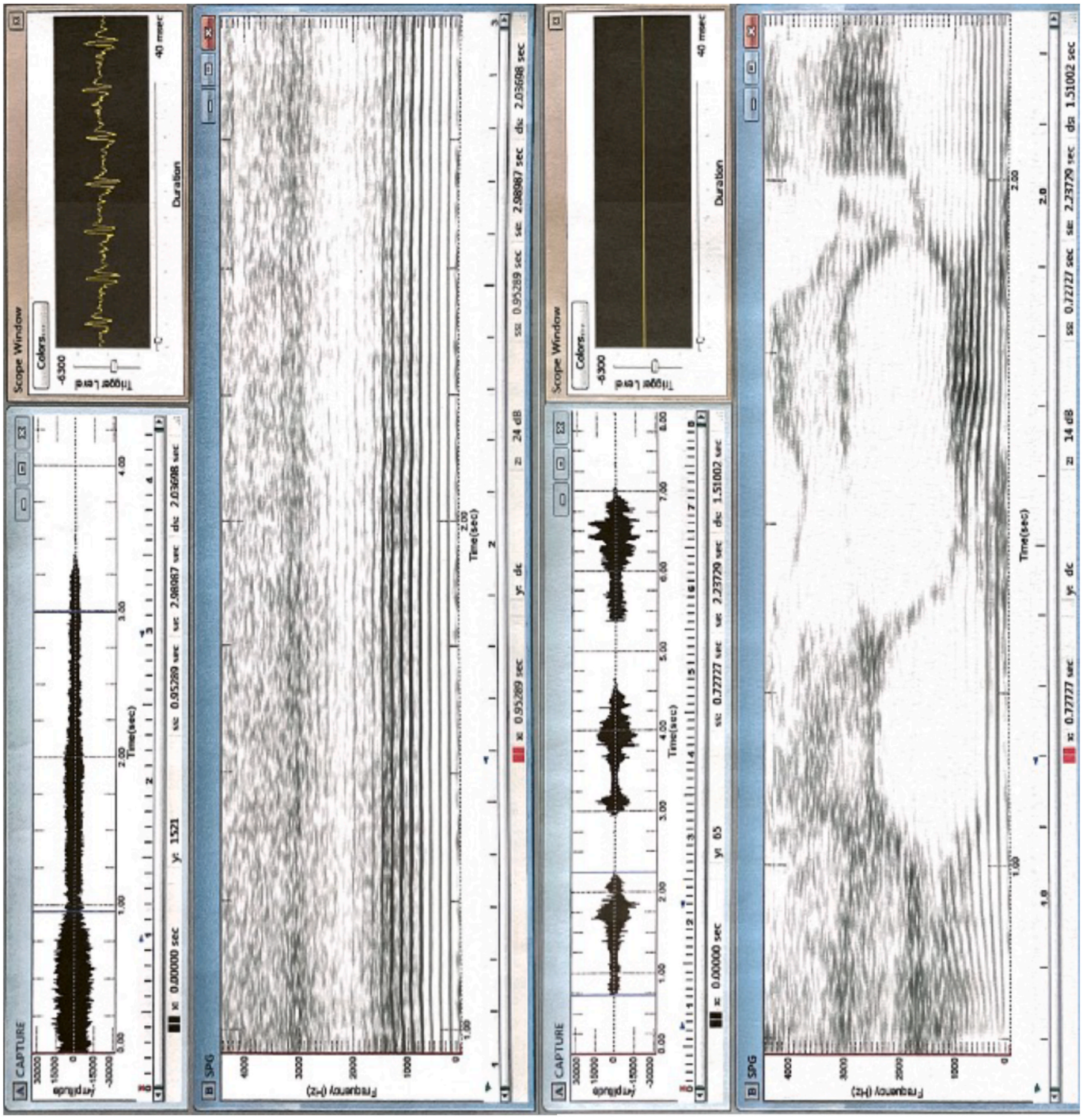


FIGURE 4. Spectrogram of vocal /a/ and word /aiuole/. Class II according to the classification of Yanaghiara modified by Ricci Maccarini and De Colle in a patient with RE grade III.

grading and the spectrogram classification performed both with the vowel /a/ and with the word /aiuole/. Considering the spectral distribution of the noise components and the modifications to the harmonics, we demonstrated that in RE patients with lower grades of RE, the noise components did not predominate over the harmonics. On the other hand, in patients with a higher grade of RE the harmonics were not present above 2000 Hz and only the noise component was present in higher frequencies (Figures 3 and 4). Similar results were found with the spectrograms of the word /aiuole/ with slight alterations and evidence of harmonic components mixed with the noise components contained in the formantic region of the vowels /a/, /i/, /u/, /o/, /e / in the lower grades of RE. Whereas more evident alterations, such as slight noise components which appear in the higher frequency regions (3.000–5.000 Hz) and of noise components which predominate over harmonic components in the second formant of /e/ and /i/ as well as in cases of high RE classification. To our knowledge, no other studies in the literature reported results of spectrogram analysis in the RE population. Additional prospective studies should be conducted to evaluate the impact of medical/surgical therapy on spectrographic findings.

LIMITATIONS OF THE STUDY

A limitation of the present study concerns the paucity of male patients in the study sample. Because of the small sample size, a comparative analysis between males and females was performed, but was not statistically significant. However, F0, which is a gender-influenced acoustic parameter, was reported separately by gender and our results did not differ from the current literature. Another limitation of the present study is the fact that, due to the retrospective nature of data collection, we were unable to conduct a multivariate analysis to explore the influence of risk factors on RE grading.

CONCLUSIONS

Patients with RE have different vocal acoustic values to the euphonic subject which can be clearly identified by multidimensional analysis. The acoustic analysis of the voice can highlight a range of parameters that correlate to the differing degrees of RE. The parameters NHR, jitt%, shimm %, and MPT would seem to be the values with the greatest variation according to their grading. Vocal spectroacoustic analysis has shown a significant correlation with the RE grading and for this reason it can be considered a semi-objective, stable, reproducible, and easy to perform parameter that could be used now for an acoustic assessment before and after medical and surgical therapy and in the application of forensic medicine.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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