Perturbation and Nonlinear Dynamic Analyses of Voices from Patients with Unilateral Laryngeal Paralysis

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Summary: This study used perturbation methods (eg, jitter and shimmer) and nonlinear dynamic methods (eg, phase space reconstruction and correlation dimension) to analyze sustained voices generated by normal subjects and patients with unilateral laryngeal paralysis. We found that normal and pathological voices had low-dimensional dynamic characteristics. For nearly periodic voices, jitter and shimmer values of pathological voices from patients with unilateral laryngeal paralysis were significantly different from normal voices. For nearly periodic and aperiodic voices, the correlation dimensions of pathological voices were statistically higher than normal voices. Receiver operating characteristic analysis was used to evaluate the diagnostic performances of jitter, shimmer, and correlation dimension. High sensitivity and specificity of these three acoustic analyses in distinguishing unilateral laryngeal paralysis patients from normal subjects were found. We concluded that combining traditional perturbation analysis and nonlinear dynamic analysis might provide efficient descriptions of pathological voices and represent a valuable tool for clinical diagnosis of laryngeal paralysis.

Key Words: Jitter—Shimmer—Nonlinear dynamic analysis—Correlation dimension—Laryngeal paralysis.

INTRODUCTION

Laryngeal paralysis is a neurogenic voice disorder caused by injury to the nerves that innervate the larynx: the recurrent laryngeal nerve, the superior laryngeal nerve, and the vagus nerve.[1–3] This condition, which can cause the glottis to remain continuously open, can be serious for patients because of resulting difficulties in breathing, coughing, and speaking. Injuries to these nerves also affect the muscles that control biomechanical parameters of the vocal folds, such as vocal fold tension. This tension causes asymmetries in the vocal folds; this might induce pitch and volume changes during speech as well as irregular vocal fold vibrations.[2–4] In addition, the glottal gap produced by laryngeal paralysis leads to glottal air leak, turbulent noise, and decreased voice intensity.[5] Perceptually, unilateral laryngeal paralysis voices are often described as breathy and rough.

Measures of acoustic perturbation, including jitter and shimmer, have traditionally described voices

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from patients with laryngeal paralysis. These objective features provide a noninvasive, quantitative assessment of vocal quality. Jitter refers to the measure of short-term (cycle-to-cycle) variation in the fundamental frequency of a voice signal. Shimmer refers to the measure of short-term (cycle-to-cycle) variation in amplitude. In a study designed to validate the ability of acoustic perturbation measures to describe the paralysis voice, Hartl et al[6] found that paralysis voices subjectively described as breathy and rough were associated with increased jitter and shimmer measurements. Jitter and shimmer have also been found to be potentially valuable in objectively evaluating the effectiveness of unilateral laryngeal paralysis treatments. For instance, Pearl et al[7] and Reijonen et al[8] found that injection laryngoplasty and injection augmentation, respectively, decreased postoperative jitter and shimmer measurements in unilateral laryngeal paralysis patients.

On the other hand, recent studies have shown that these two perturbation measures can only reliably analyze nearly periodic signals and might not be suitable for analysis of aperiodic or chaotic signals.[9–14] Consequently, nonlinear dynamic methods have been applied to study laryngeal paralysis by using computer models and voice analysis.[15,16] Voice production is a nonlinear process involving biomechanical and aerodynamic effects. Many aspects of the laryngeal system exhibit nonlinear behavior, including the nonlinear stress-strain characteristics of tissues, the relation of glottal pressure to airflow, and nonlinear vocal fold collision.[17] Findings in nonlinear models show that irregular and aperiodic vibration may be associated with chaos.[15,18] Ishizaka and Isshiki[4] used a nonlinear vocal fold model to study the effects of asymmetric tension and glottal closure on vocal fold vibration and found that laryngeal paralysis might yield irregular vibrations. By modeling the vibrations of vocal folds with superior laryngeal nerve paralysis and recurrent laryngeal nerve paralysis, Steinecke and Herzel[15] found that tension imbalances between the right and left vocal folds might induce subharmonics and chaos. Nonlinear dynamic methods have been shown to compliment traditional perturbation methods because they can describe pathological voices that are aperiodic.[19] For example, Giovanni et al[16] found that the maximal Lyapunov exponent, a nonlinear dynamic parameter, and the perturbation measures statistically differentiated between normal voices of healthy subjects and pathological voices of patients with unilateral laryngeal paralysis. Therefore, the application of nonlinear dynamic analysis in conjunction with traditional perturbation analysis might improve our understanding of disordered voices and aid in the diagnosis of pathologies such as laryngeal paralysis.

In this study, correlation dimension, a nonlinear dynamic measure, and jitter and shimmer, two traditional perturbation measures, were applied to analyze voices from patients with unilateral laryngeal paralysis. We used the correlation dimension proposed by Grassberger and Procaccia[20] because it is a simple yet effective method for quantifying aperiodic behavior in biomedical systems such as those in cardiology[21] and neurology.[22] The abilities of jitter, shimmer, and correlation dimension to differentiate pathological from normal voices were investigated to evaluate the capabilities of these objective measures.

MATERIAL AND METHODS

Database

The voice samples examined in this study were selected from the Disordered Voice Database, model 4337, version 1.03 (Kay Elemetrics Corporation, Lincoln Park, NJ), developed by the Massachusetts Eye and Ear Infirmary Voice and Speech Lab.[23] This database includes 57 normal voices (38 women and 19 men) ranging in age from 22 to 55 years and 67 unilateral laryngeal paralysis samples (34 women and 33 men) ranging in age from 15 to 80 years. Subjects were asked to sustain the vowel "a," and voice recordings were made in a soundproof booth on a DAT recorder at a sampling rate of $f_s = 44.1$ kHz. Voice signals were then analyzed with jitter, shimmer, phase space reconstruction, and correlation dimension.

Data analysis

The acoustic perturbation measures (percent jitter and percent shimmer) were obtained from the *Multi-Dimensional Voice Program* (*MDVP*), model 5105, Version 2.0 (Kay Elemetrics Corporation). In the application of MDVP for voice analysis, previous studies have shown that perturbation analysis of aperiodic voices is unreliable and that nearly periodic