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Quasi-periodic Perturbations in Pathological Vocal Fold Vibration

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It is generally known that many cases of rough voice are characterized not by simple random perturbations but by quasi-periodic perturbations in the speech wave. However, there are few studies on the characteristics of perturbations in vocal fold vibrations associated with this type of voice. In the 1970s, Hirano et al reported a series of high-speed motion picture studies of pathological vocal cord vibration. In their studies, there was only one case which was explicitly described as having perturbation of a quasi-periodic nature. It was a case of the unilateral paralysis of the recurrent laryngeal nerve. It was reported that in this patient, the left and right vocal folds had different vibratory frequencies and one vibratory cycle of the normal side dropped out at every 5~6 vibratory cycle of the diseased side. This pattern of vibration was similar to that reported by Ward et al[3] for a special normal subject with the ability to produce diplophonia without any pathology.

The lack of data on this type of vocal fold vibration is presumably due to the fact that in the past, a frame by frame analysis of high-speed motion pictures was generally limited to a period of a few vibratory cycles because it was a time consuming task. We have been conducting studies of pathological vocal cord vibration using a high-speed digital image recording system developed by the present authors[1]. The system is compact and simple to operate and, thus, is suited for pathological data collection. The system is also convenient for simultaneous recording of the speech signals, and for the analysis of the relationship between pathological voice and the pathological vocal cord vibration. Furthermore, since all the processes involved in the data recording are computerized, analyses of vocal fold vibration over a period of a relatively large number of vibratory cycles have become feasible.

In a previous study[4], we reported on vocal cord vibration in three cases of "diplophonia" similar to that reported by Hirano et al[2]. Since then, we have continued data collection for patients whose voices are perceptually judged as exhibiting diplophonic voice quality. Up to now, we have succeeded in recording laryngeal images for another 10 subjects. All of these basically show quasi-periodic fluctuations in their vocal fold vibrations. The present paper describes the nature of the quasi-periodic fluctuations observed in these cases.

Experimental Method

Ten patients perceptually identified as having diplophonic voice quality were subjected to a high-speed digital image recording of their vocal fold vibration. The system consists of an oblique angled solid endoscope, a camera body containing an image sensor, and a digital image

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memory. The laryngeal image obtained through the endoscope is focused on the image sensor. The image sensor is scanned at a high-frame rate, and the output video signal is fed into the image memory through a high-speed A/D converter. Digitally stored images are then reproduced consecutively as a slow-speed motion picture. The frame rate was 2600 per second with the number of pixels 128 x 32.

The degree of diplophonic voice quality generally varied from phonation to phonation within patient. In the data recording session, the subject usually produced 3~5 phonations. In the following, the pattern of the vocal fold movement in a typical diplophonic sample for each subject are presented.

In the present study, a quantitative analysis of the movements of the vocal folds was conducted as follows. On the recorded images, the glottal opening was identified as the dark area with a brightness value lower than a given threshold. A horizontal scan line at an appropriate position on the glottal opening was selected, and the edge points of the dark on this line were taken as representing the movements of the vocal folds.

Left-Right Imbalance

1) Quasi-periodic perturbation over 4~5 pitch periods

Figure 1 shows the movements of the vocal folds in three cases which showed quasi-periodic perturbations over 4~5 pitch periods. It can be seen in the figure that the pattern of the vocal fold movements are essentially similar to those reported by Hirano et al and also to those reported in our previous paper.

It was observed that there was a difference in vibratory frequency between the left and right vocal folds, and that the phase difference between the vocal cords varied with time quasi-periodically, resulting in a quasi-periodic variation in the speech signal. When the movements of the vocal cords were nearly in phase, the glottis showed a period of complete closure, and the excitation in the speech wave was strong. During successive cycles, the phase difference became progressively larger. The glottal closure became incomplete, and the excitation in the speech wave weakened. At some point in time, the phase difference between the left and right vocal folds was reset and the vibrations resumed in synchrony.

However, each of the three cases shown in Figure 1 exhibits a different pattern of phase resetting. In case 1, 5 vibratory cycles of the left vocal fold correspond to 4 vibratory cycles of the right vocal fold. It appears that in this case the vibratory phase of the right vocal fold tends to be delayed relative to that of the left vocal fold. Then, at some point in time (A in the figure), the vibratory cycle of the right vocal fold with a delayed phase gets longer and the phase difference between the left and right vocal folds is cancelled out. As a result, the vibrations of the left and right vocal folds resume synchrony. Apparently, at this point, one cycle of the vibration of the right vocal fold drops off. In contrast to this, in case 2, the vibratory cycle of the left vocal fold which shows a phase advance relative to the right vocal fold gets longer at point A in the figure, and the vibrations of the left and right vocal folds synchronize. Consequently, in this case, the number of vibratory cycles of the left and right vocal folds over a given period remains the same on average.

Case 3 may be considered as an intermediate case between case 1 and the case 2. Here, the right vocal fold which has the delayed phase exhibits a small additional vibration at point A in the figure. Whether or not this vibratory movement can be counted as one vibratory cycle is a matter of degree.

2) Quasi-periodic perturbation over 3 pitch periods

In cases 4 and 5, shown in Figure 2, the pattern of the vocal fold movements is essentially the same as that in Figure 1, that is, there is a difference in the vibratory frequency of the left and right vocal folds. However, it appears that in these cases, the difference in the vibratory frequency of the left and right vocal folds is larger than that in Figure 1. The ratio of the vibratory cycles of the left and right vocal fold is 3 to 2. Consequently, the phase resetting takes place in a shorter period.

In case 4, the closed period can be seen at every cycle of the vibration of the left vocal fold, and there is a corresponding excitation in the speech wave. As a result, the pitch period of the speech clearly corresponds to the vibratory cycle of the left vocal fold. However, in case 5, the glotal closures are very weak in the second and third cycles of the vibration of the left vocal fold. Thus, the 3 vibratory cycles of the left vocal fold and the 2 vibratory cycles of the right vocal fold apparently correspond to one pitch period on the speech wave. The EGG signal also shows a similar trend.

Anterior- Posterior Imbalance

Figure 3 shows two examples of quasi-periodic perturbation in vocal fold vibration which appear to be related to the imbalance between the anterior part and the posterior part of the vocal folds.

Case 6 is a case of a localized polyp. It appears that the vibratory characteristics are different between the posterior and the anterior part of the vocal fold relative to the polyp. The curves in the figure reveal that the anterior part vibrates 5 cycles during the 4 cycles of vibration in the posterior part. Thus, as in the cases of left-right imbalance, the phase difference between the posterior and anterior part varies with time, and, at some point, the anterior part of the glottis is open when the posterior part of the glottis is closed. At this point, the glottal closure is, as a whole, incomplete and the speech amplitude is small.

Case 7 is an another example of anterior-posterior imbalance. This subject has an accumulative lesion around the middle of the vocal cords. Her vocal cords tend to show a large phase difference between the anterior and posterior parts. The vocal folds of this subject also tend to show the left-ight imbalance, that is during the four vibratory cycles of the right vocal fold, the left vocal fold shows five vibratory cycles. It can be seen in figure 3 that at every fourth cycle of the vibration of the right vocal fold, the left vocal fold exhibits two cycles of vibration during one cycle of the right vocal fold vibration. It is further noted that in the case of this subject, this abnormal pattern of vibration occurs at different vibratory cycles for the anterior and posterior part of the vocal folds. The cycles of this abnormal vibratory pattern is also characterized by the incomplete closure of the glottis. Thus, there is a quasi-periodic vibration in the speech amplitude over 4 vibratory cycles of the right vocal fold.

Comments

In the present study, the vocal cord vibration in the ten pathological cases were examined by the high-speed digital image recording system whose voices were perceptured judged as diplophonia.

The results show that all of the cases examined here has difference in the vibratory frequency between the different part of the vocal folds, i.e. between the left and right vocal folds or between the anterior and posterior part of the vocal folds. This difference causes quasi-periodic change in the phase difference between the vibration of the different part. When the phase diference is large, the glottal closure is incomplete, resulting in a quasi-periodic variations in the speech amplitude. Although the possibility of other mechanisms of quasi-periodic variation can not be denied, the result of the present data suggest that the difference in the vibratory frequency among the different part of the vocal folds is the major source of the diplophonic voice quality.

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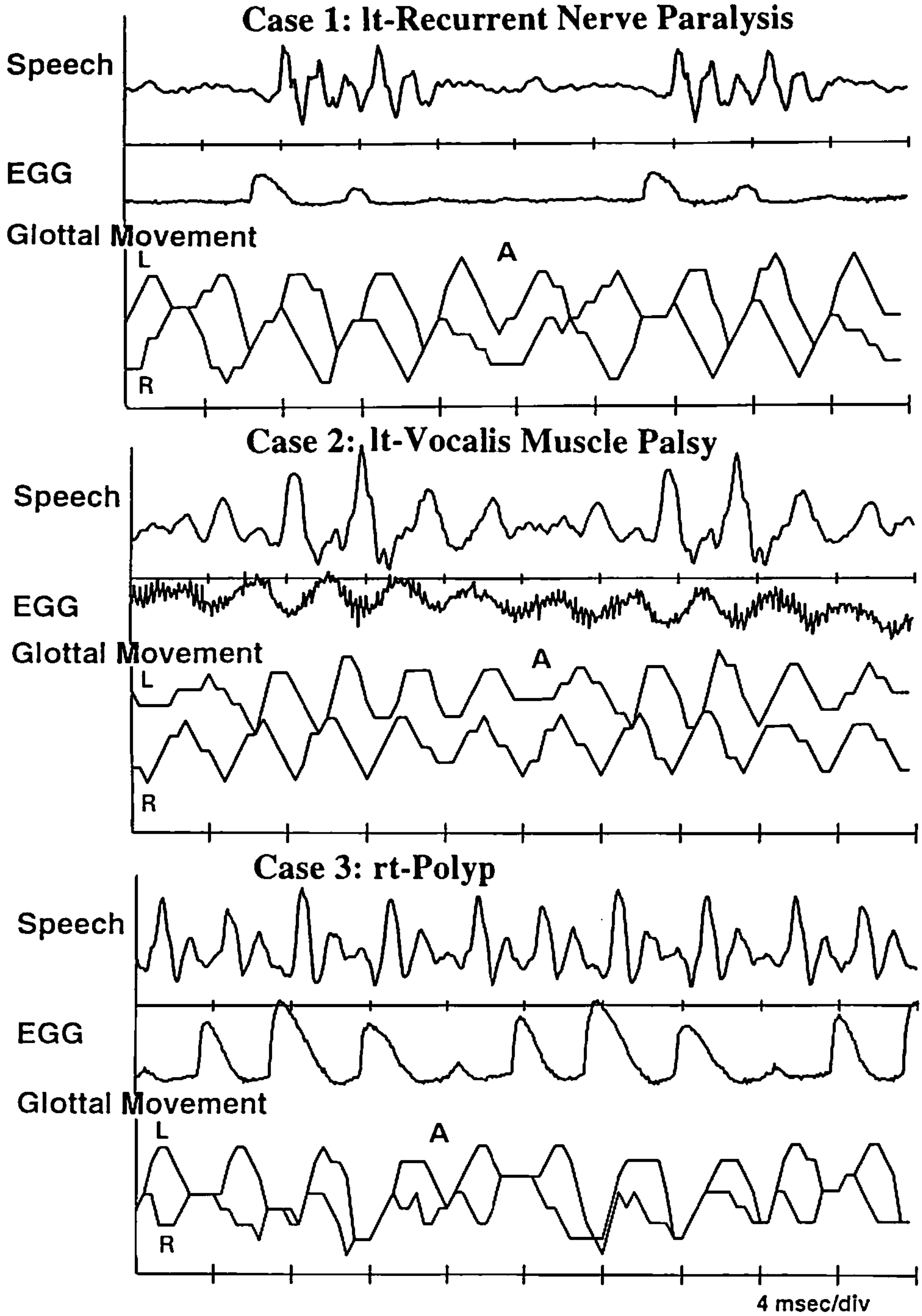

Figure 1 Three cases of left-right imbalance with quasi-periodic perturbation over 4~5 vibratory cycles.

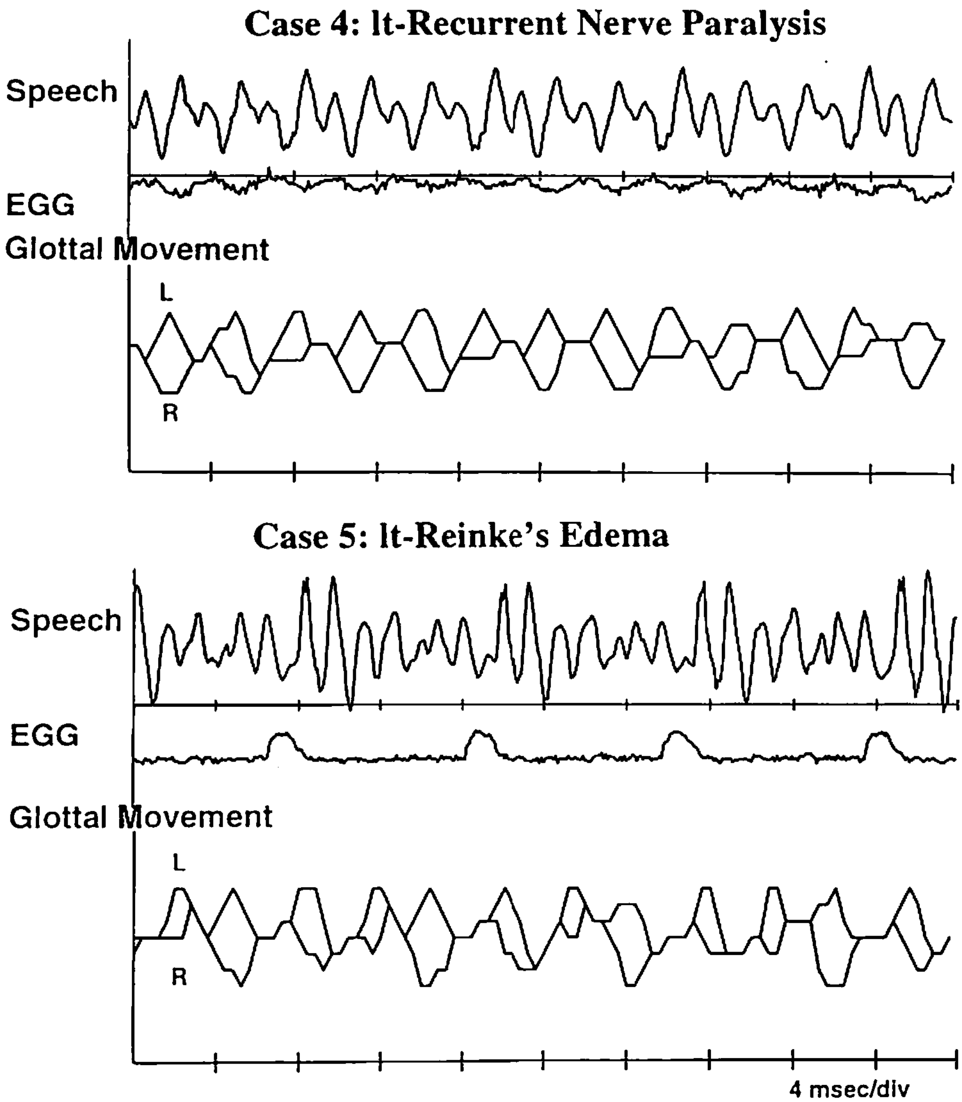

Figure 2 Two cases of left-right imbalance with quasi-periodic perturbation over 2~3 vibratory cycles.

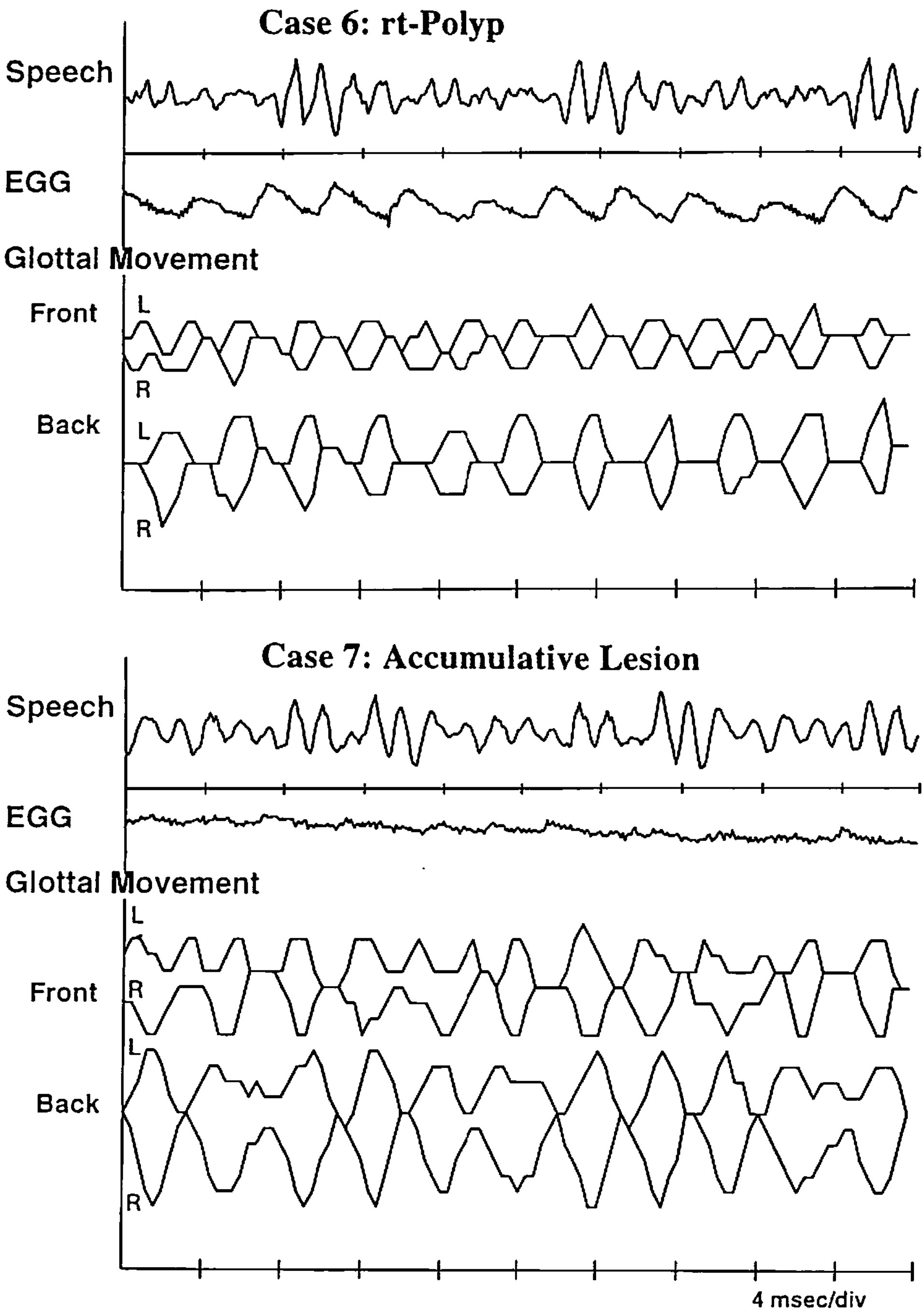

Figure 3 Two cases of anterior-posterior imbalance.