VALIDATION OF ELECTROGLOTTOGRAPHIC PATTERNS IN VOICE DISORDERS USING STROBOSCOPY

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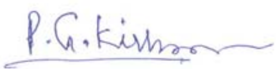

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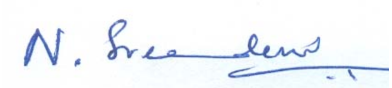

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Definition of Voice impairment as put forth by ASHA (1993) states it as "The abnormal production and/or absence of vocal quality, pitch, loudness, resonance, and/or duration which is appropriate for an individual's age and/or sex." More contemporary definitions have shifted from a focus on the voice signal as such to a focus on the individual capabilities. Stemple (2000) states that "a voice disorder exists when either the structure or function or both of the laryngeal mechanism no longer meet the voicing requirements established by the mechanism for the speaker".

The incidence and prevalence of voice disorders is soaring up in the recent past. The National Institute of Deafness and Communicative Disorders, a Division of the National Institutes of Health, estimates 7.5 million individuals to have diseases or disorders of voice caused by overuse of the voice, upper respiratory tract infections, vocal fold lesions, laryngeal cancer, and other laryngeal pathologies. . Boone and Farlane (1988) reported the prevalence rates of voice disorders in school-aged children to be approximately 5% - 9% whereas Powell, Filter and Williams (1989) reported much higher prevalence rate of 23.9% in the same age group of children. In another study, Roy, Merrill, Gray and Smith (2005) reported the lifetime prevalence of voice disorder to be 29.9%, with 6.6% participants reporting current voice disorder in the random sample (n = 1,326) of the general population of adults in Iowa and Utah.

Roy, Stemple, Merill and Thomas (2007) studied epidemiology of voice disorders in the elderly and reported a life time prevalence of 47% in a group of 117 participants. Munier and Kinsella (2008) conducted a study on the prevalence of voice problems in 550 primary school teachers. The following results were observed from their study: 27% of the teachers had voice problems, 53% of them had intermittent voice problems, and just 20% of them reported no voice problems. High rates of incidence and prevalence of voice disorders, increasing on an exponential basis, emphasize the crucial need to investigate and assess the diagnostic voice measures in more accurate manner and subsequently delineate the apt line of management.

1.1. Phoniatric (voice) evaluation and its measures

Phoniatric consultation is majorly sought by professional voice users who spot minor breathiness, hoarseness, intensity problems, or timbre variations within their phonatory range and by non professional voice users experiencing any significant vocal handicaps. A rational challenge for accurate phonatory analysis of vocally handicapped individuals is to choose those instrumental tools that best portray and describe vital attributes of voice production. Ample of apparatus are accessible to the voice clinician for use during the assessment and measurement of voice disorders. Some of these are perceptual evaluation, quality-of-life measures, and acoustic measurements. Issues with validity, reliability and certain other confounding factors have hampered the consensus on any single measure being considered as paramount for identifying the type, degree/severity of voice disorders. Instrumental measures of vocal function are a fundamental and vital component of the clinical process, rather than just being supplementary to assessment and treatment. The aim of instrumental evaluation in speech pathology is to provide explanatory accounts of disabilities rather than simple descriptions-however useful these may be as a step towards the definition of a problem (Abberton, Howard and Fourcin 1989). One such edifying objective assessment tool is the Electroglottograph or the Electrolaryngograph.

1.2. Electroglottography

Electroglottography (EGG) reflects variations in the electrical impedance which supposedly result from changes in the contact area of vocal folds during phonation. In its initial phases of discovery, the electroglottograph was proposed as an instrument that would enable the investigator to explore the vocal folds movement without having to directly look at the larynx (Karnell 1989). Electroglottography (EGG) is a technique used to examine laryngeal movements, more specifically, the movements of vocal fold which provides for an indirect observation of the degree of contact between tissues in the neck (Titze, 1990). It is entirely noninvasive, impermeable to ambient noise, innocuous and yields clear-cut information about the vibratory behavior of vocal folds during phonation.

The theory behind the working principle of EGG is put forth by Titze (1990) in the following manner. "Tissues within the neck act as a conductor, whereas airspace between the electrodes is bypassed by the electric field lines, thereby narrowing the conducting path. On the passage of a high frequency electric current signal (2-5 MHz typically), the overall conductance between the electrodes is increased, therefore, by the reduction of air gaps. Specifically, as the vocal fold tissues make contact, the conductance increases; this is interpreted as glottal closing. Conversely, decrease in the conductance is interpreted as glottal opening. The EGG signal measures the sealing of the glottis". With regard to modeling, a number of imperative temporal features of the EGG waveform are commonly explained on the basis of pre phonatory glottal shapes and tissue dynamics. These include sharpness of the EGG waveform rise, flatness at the top, knee in the contact release phase, and breadth of the contact pulse (Titze 1990). Interpretation and inference of the underlying vocal pathology through the EGG can be best accomplished by means of description of its morphology and the numeric values of its various quotients.

Owing to the presence of a few pitfalls associated with EGG, an all-too- naive interpretation of the data may prove adverse, especially in clinical applications. It is vital for the voice professional to be aware that the EGG does not truly reflect vocal folds vibrations as such, but variations in patterns of the contact area between them. This too is just an approximation, as the cause of glottographically detected impedance changes till date are not vividly clear, nor is the relevance of vocal fold contact area variations to the acoustic voice signal (Kitzing, 1990). Hence this is not the only assessment tool that can be employed in analyzing the voice parameters and arriving at a diagnostic inference. As this tool paves way for an indirect inference of laryngeal vibratory behavior, a more direct glottal visualization system in addition will aid in an auxiliary comprehension of the laryngeal behavior and its functioning. Validity of EGG elucidation necessitates a correlation or an association of the EGG waveform with certain other measurement tools of glottal function. One such comprehensive glottal visualization technique is the *Video-stroboscope.*

1.3. Videostroboscopy

Laryngeal stroboscopy creates an evident slow motion view of periodic vocal fold vibrations by sampling effectively the successive phases of movement across successive vocal fold cycles. This special instrumental technique provides for magnified and slow motion viewing of the vocal cords in action. It endows for an accurate diagnosis of conditions and diseases of the vocal folds and certain supra glottal structures including mass lesions, deviancies of vocal cord motion or mobility, inflammatory conditions, arterial or blood supply discrepancies, scarring lesions and other conditions.

The **Stroboscopic** effect was discovered in 1833 by Stampfer of Vienna. The effect is based on an optical illusion that is caused by persistent visual images. Rapid periodic motions, such as vibrations or rotations are not ordinarily resolvable by the unaided eye. These can be made visible by illuminating with very short flashes of light which are synchronous with the motion of object under observation. Exact coincidence of the frequency of light flashes and the position of the moving object provides a sharp and clear still picture, because points at the same phase angle of the object's motion are repeatedly illuminated. Slight variations between the frequency of the flashing light source and the frequency of object's motion produces the slow motion effect (Wendler, 1992).

Present stroboscopes indicate the frequency of the phonatory signal and, occasionally, its intensity. With phase variability of the vocal folds, their dynamic aspects can be assessed. Coupling the instrument to video recording systems to store results for research, teaching, and treatment are in clinical vogue. Characteristic features to be observed from the video stroboscopic recording include: the glottis closure patterns, mucosal wave generation and its vibratory amplitude (which provides for viewing the flexibility of mucosa and its freedom from the underlying body of the vocal fold), phase symmetry and periodicity of vibrations. In addition, the system allows for observation and documentation of actions of other supraglottic structures namely the epiglottis, ventricular folds, arytenoids etc. The addition of the strobe light during the procedure paves way to assess the finer and discrete parameters of vocal fold vibration and yields quantitative and qualitative information about laryngeal mechanism.

1.4. Need for the study

The Electroglottogram has been used extensively by Speech-Language Pathologists as a most viable non invasive instrumental measure of voice disorders. Nonetheless, as the instrument is associated with a few pit falls, relying solely on it for the purpose of phonatory diagnosis has not been incredibly flourishing. Kitzing (1990) reports that with rising insecurity relating to the reliability of the EGG signal it is to be combined and validated by means of other methods like videostroboscopy. The advent and use of Videostroboscopy in the recent past has accelerated the accuracy of SLPs in analyzing finer and more discrete attributes of the vocal mechanism. However in developing countries like India, not a huge corpus of SLP's are trained hands on in performing stroboscopy and owing to the exuberance associated with the procedure wide use of stroboscopy is constrained. Nevertheless, in general, it is the combination of EGG and stroboscopy that endows with adequate information from instrumental evaluation regarding diagnosis and management of voice disorders. At least establishing the validity and reliability measures of EGG through visualization techniques like stroboscopy will assist the use of EGG with more authenticity. With this facility being currently available at AIISH, there is a necessity and scope to trace the relationship between the Electroglottogram patterns with the findings on videostroboscopy. This would enhance the utility and extent of reliability factor of EGG in clinical vogue, particularly considering the dearth of SLPs in India trained hands on in performing Videostroboscopy.

1.5. Aim

As no single instrumental measure is sufficed in itself for providing accurate, apparent and detailed assessment of the glottis and its functional behavior, phonatory analysis can be triumphant especially when it is validated with other instrumental measures. Hence the present study was intended to track the association between findings of EGG with that of Videostroboscopy and to arrive at an inference regarding the extent of reliability on EGG in clinical practice.

1.6. Objectives of the study

1. To estimate a qualitative relationship between EGG patterns and the findings on videostroboscopy.

2. To estimate the sensitivity and specificity of EGG waveform patterns and stroboscopic findings in recognizing anatomical and physiological vocal fold discrepancies.

3. To compare across age ranges the qualitative relationship between EGG patterns and stroboscopic findings.

CHAPTER II

REVIEW OF LITERATURE

An edifying objective gold standard tool for the assessment of voice disorders is the Electroglottograph. Electroglottography (EGG) is a non-invasive electrophysiological technique that allows observation of the properties of vocal folds vibration by measuring the electrical resistance/conductance between two electrodes positioned on the neck approximately over the thyroid cartilages. Described by Fabre in 1959, EGG has ever since been used to supplement data obtained from other techniques providing information precisely about vocal-fold contact, significant for physicians and voice therapists. EGG is non-invasive, innocuous and an inexpensive technique that generates a signal effectively free of supraglottal influence, and hence is of immense value in disambiguating vocal and articulatory phenomena. Of supreme importance, EGG provides insight into certain significant aspects of vocal fold function that is not accessible by any other means.

2.1 *A brief on the historical emergence of EGG*

In 1957 Fabre described the application of impedance methods, which previously was used to investigate arterial pressure, to assess laryngeal function. He reported that "high-frequency glottography" (as he then termed Electroglottography) would permit exploration "of the details (laryngeal phenomena) under physiologic conditions of sound production, without having the instrument encumber the oral cavity. Baken (1992) reported that “the frequency of glottal vibration, the details of opening and closure will thus be observable in both normal and pathologic cases and for all kinds of sounds, without restriction”. As the original and improved EGG methods became more widely available (Fabre, 1959, 1961; Decroix, 1958; Vallancien, 1967; Van Michel, 1967, 1969 & Fourcin & Abberton, 1971,

1972) investigators, especially in francophone countries, rapidly adopted the new technique to inspect normal glottal behaviour (Decroix, 1958; Fabre, 1958 & Muller, 1962), respiratory behaviour of the larynx (Fabre, 1958), and disorders such as stuttering (Muller, 1964). This method was later recruited as an investigatory tool in the intense battle of the Myoelastic-aerodynamic (Van den, 1958) and Neurochronaxic (Husson, 1953) models of voice production (Decroix, 1958; Muller, 1962; Lebrun & Deleval, 1971). Adrian Fourcin (at University College, London) emerged as one of the leading pioneers to advocate the use of EGG technique to rehabilitate a significant range of voice and speech disorders (Baken, 1992).

Early 1980s witnessed a significant increase in the application of EGG in both the research and the clinical realms driven by an enhanced interest in voice disorders, advances in vocal physiology, greater clinician sophistication in the objective assessments, and the commercial availability of relatively inexpensive instrumentation (Baken, 1992).

2.2 *Working principle of the EGG*

2.2.1 *Impedance and the larynx*

In laryngeal examination, the behaviour of vocal folds in action is of principal interest. During phonation, the vocal folds are periodically separated by the glottis (an air-filled space). The vocal fold tissue is a moderately good electrical conductor and the air is an extremely poor conductor. Thus, during the glottal cycle, the electrical impedance across the larynx increases (as the glottis opens) and falls (as the vocal folds come into greater intimate contact). The contrary happens with respect to electrical conductance. Thus, impedance probing would be ideally suitable in portraying the finer particulars of laryngeal functioning.

Impedance measurement techniques of the larynx present particular challenges, and hence, the EGGs are specifically designed to comprise circuits that are intended to (a) minimize the effect on the EGG owing to changes in perilaryngeal structures; (b) compensate for laryngeal motion with respect to the electrodes; (c) maximize the contribution of glottal region to the final output; and (d) compensate for sluggish changes of overall impedance (due to head movement/changes in skin moisture) and adjust to impedance variations reflecting normal anatomic disparity among individuals.

2.2.2 *Basic Instrumentation of EGG*

The laryngograph (Fourcin & Abberton, 1971) is a practical instrument designed to monitor vocal fold closure, giving a basis for the measurement of aspects of vocal fold vibration occurring during voiced sounds. The device operates by sensing the electrical conductance between two electrodes placed superficially one on either side of the neck of the speaker at the level of the larynx (Fabre, 1957). Each gold-plated electrode consists of an inner disk surrounded by an outer guard-ring held in position by means of an elastic neckband. The laryngograph monitors the varying electrical conductance between the electrodes in terms of the current flowing between them on application of constant voltage. Its output waveform (Lx = Larynx excitation) gives this current flow as a function of time. Current flow will be maximum when the vocal folds are in contact and minimum when they are apart. This point is basic to a proper understanding of device operation and subsequent Lx waveform interpretation. Acoustically, the closure of vocal folds produces the main excitation pulse in each laryngeal cycle (Abberton, Howard & Fourcin, 1989).

To elaborate, a much stable oscillator which generates a high-frequency current is coupled to the neck by means of a set of electrodes having few square centimetres area. Depending on the particular instrument; the carrier signal generated by the oscillator may have a frequency ranging from 300 kHz to a few megahertz. A current of 10 mA or less is employed, which typically results in a voltage across the neck in the order of 0.5 V.

Impedance deviations in the current path result in proportional variations in the alternating current or, in the voltage drop between electrodes. This amplitude signal is an evidence of the trans-neck impedance over time.

2.3 *The ideal laryngeal waveform*

Baken (1992) gives a vivid description of the emerging laryngeal waveform from the underlying physiological events of the vocal mechanism in the following manner. The Laryngeal waveform as illustrated in Figure 2. 1 represents an ideal trace of normal phonation. Vocal fold contact area is represented to increase upward along the y axis. There is no established convention governing the direction of this axis and inverted versions are common in the literature.

The relationship between gross features of the Laryngeal waveform and the major phases of the glottal cycle can be put forth in the following manner: a flat segment (1) that represents minimal contact of the vocal folds is considered to symbolize the period during which the focal folds are separated. (It is during this phase that peak glottal flow occurs.) This interval ends abruptly at inflection point ‘**a**’ as the contact area begins rapidly (2), defining the advancement of glottal closure. Point ‘**c**’ indicates the instance of maximal closure and the closed phase may extend for at least the length of the plateau (3). Suddenly, at the point‘**d**’, contact area begins to diminish again. The decrease continues (4) until a minimum is again reached at point ‘**f**’, when the glottis opens.

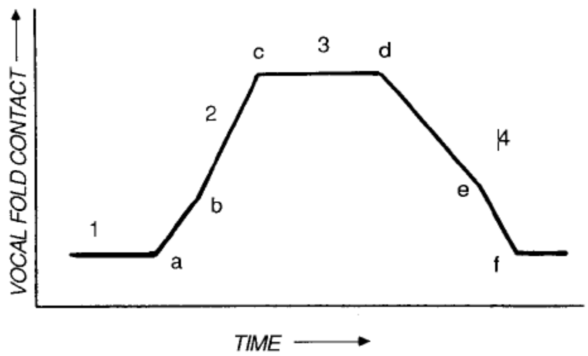


Figure 2.1, Ideal EGG record of normal phonation (Source: Baken, 1992)

Childers' modelling, combined with observations by Rothenberg (1981) and Baer, Lofqvist, and McGarr (1983) allows a more comprehensive interpretation of the idealized waveform of Figure 2.1.

- *Point a:* the lower margins of the vocal folds make initial contact, signalling the start of the closing phase.
- *Interval a-b:* Lower margin approximation proceeds. In some instances of closure, the folds remain virtually parallel and closure occurs very rapidly along their entire length. In this case the slope of the *a-b* interval is great. Often, however, the folds form an acute angle, giving the glottis a V shape, and causing the zipper closure. Under these circumstances, the slope of this interval is less.
- *Point b:* upper margins of the folds make initial contact.
- *Interval b-c:* upper margin approximation spreads anteroposteriorly; glottal closure is achieved during this interval.
- *Point c:* maximal contact achieved. Closing phase ends.
- *Interval c-d:* contacting surface area remains maximal. Minimal glottal size persists.
- *Point d:* separation of the lower margins of the vocal folds begins, initiating the opening phase.
- *Interval d-e:* lower-margin separation proceeds gradually.
- *Point e:* separation to the lower-margin completed. Upper margins begin separation, often zippering in a posterior-to-anterior direction. The exact significance of this inflection point is commonly referred to as a knee in the opening phase. The abrupt change in slope occurs at the time when a bridge of mucus connecting the separating vocal folds suddenly ruptures.

- *Interval e-f:* upper margins of the vocal folds continue to separate. Glottal opening occurs, and glottal length and glottal width increase.
- *Point f:* contact between the vocal folds reaches its minimum. Glottal length is maximal.
- *Interval f-a:* no change in vocal fold contact. Glottal width (presumably) peaks.

The following vital conclusions result from consideration of the model (Baken, 1992):

1. Relative contact area is alone represented by EGG. Hence, maximal contact area need not necessarily indicate glottal closure. It is possible (and, particularly in loft register, not uncommon) for glottal closure not to occur at all.

2. It is likely that annihilation of the glottis occurs before maximal vocal fold contact is achieved. Hence, it is not possible to specify the precise time at which glottal closure is initially achieved.

3. As phonation requires transglottal airflow, it is possible to conclude that there is glottal opening during the f-a interval. The exact instant at which that opening occurs cannot be determined by inspection of the laryngeal record.

4. Minimal contact area is, quite noticeably maintained throughout the period that represents glottal opening.

5. Events during the times when the vocal folds are in contact show in the laryngeal record. Aberrations during the maximal contact period should be clearly indicated.

6. The occurrence of a knee in the opening phase is common, but not universal.

7. Amplitude of the laryngeal wave is not an apt correlate of vocal intensity.

8. The fundamental frequency of laryngeal wave matches the vocal fundamental frequency exactly.

2.4 *EGG technique and its inference*

The information obtained from EGG can be processed and inferred in varied ways. The generally used and most obvious method seems to be subjective or visual inspection of the wave shape of the EGG (Fourcin, 1981). To acquire objective data, durational and amplitude measurements can be carried out on different parts of the glottographic curve. These are parameterized by computing the quotients: the open quotient, contact quotient and the speed quotient (Kitzing, 1990). The measuring and computing procedure may be computerized. Abnormal EGG has been considered for analysis in 5 different ways

1. Pitch characteristics (too high or too low) (Kitzing, 1979)
2. Vibration irregularity demonstrated by F0 histograms (Kitzing, 1979, Fourcin, 1981)
3. Special features of the signal as in the case of diplophonia (Dejonckere & Lebacq, 1983)
4. Qualitative description of the modified waveform (Van Michael, 1967; Wechsler, 1977; Fourcin, 1981)
5. Spectral analysis of the waveform (Kelman, 1981).

Analyzing and drawing inferences from EGGs have been best researched upon mainly through qualitative description of their wave morphologies and quantitatively through the numerical quotients derived from them. Literature evidences a few reports attempting to quantify the characteristics of EGG signal by defining systematized events, measuring intervals between them and calculating various ratios (Dejonckere, 1981).

Further contradicting this, a few more evidences question the validity of quantitative interpretation of the glottal condition by means of EGG (Hirano, 1981) and quantitative shape related data limited considerably with respect to voice disorders (Dejonckere, 1981).

Similarly, Dejonckere (1981) reported that no specific voice disorder has been systematically investigated from an EGG point of view with respect to the shape of the waveform. Gainsaying this, Kitzing (1990) opines that the EGG waveform is of interest mostly for qualitative representations. Further, Baken (1992) anecdotes that “the laryngeal signal provides information about vocal fold function mainly by inspection and despite sporadic efforts to derive specific numerical parameters, analysis remains mostly qualitative”. In addition, there have been many other studies that establish confirmed waveform patterns to signal various voice registers and pathological voice conditions (Zagolski, 2008; Dejonckere & Lebacq, 1983; Motta, Cesari, Iengo & Motta Jr, 1990).

2.4.1 *EGG waveform patterns and quotients in vocal registers and pathological conditions*

The vocal register is usually signalled by characteristic appearance of the laryngeal waveform aiding in discriminating pathological voice function from an inapt vocal mode. Instability of laryngeal amplitude or period indicates abnormal inconsistency in the contact pattern, which is known to be associated with a large number of disorders. Instability, such as minor oscillations, in the region of the wave's peak (the time of supposed glottal closure) can rationally be interpreted as "fluttering" or rebound of vocal folds following initial contact during closing. Similarly, changes in the opening/ closing segments often indicate disturbances in vocal fold tension (Wechsler, 1977) (Baken, 1992). Mitra (2004) reported markedly rounded waveform, low peak amplitude, gradual increase and decrease in impedance and comparatively longer maximum contact phase in tense voices. Figure 2.2 illustrates the EGG waveform morphologies in varied vocal registers.

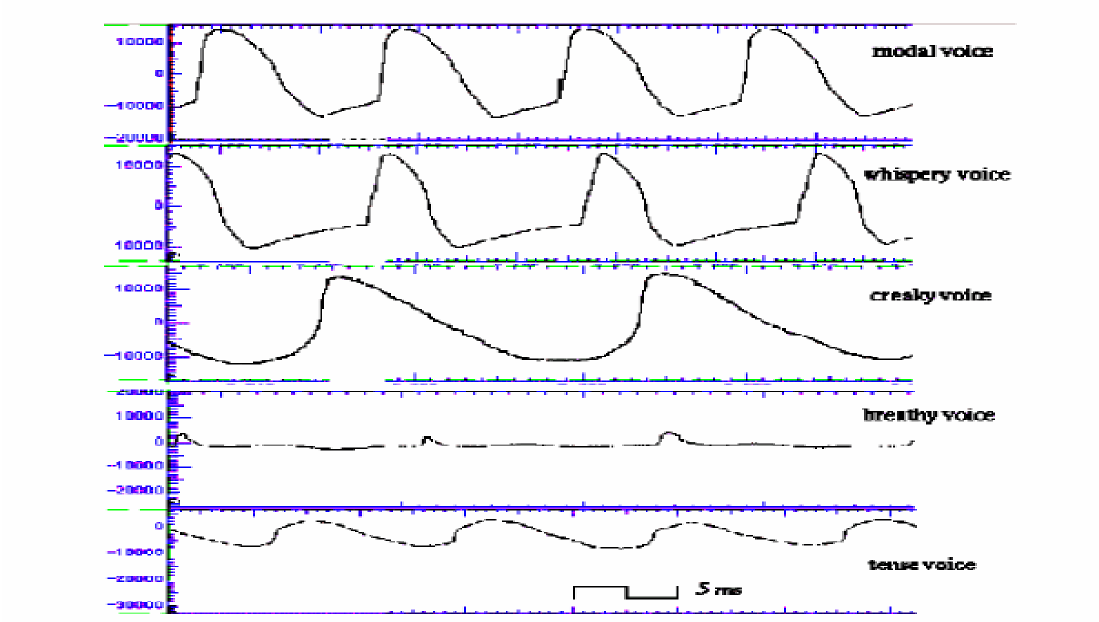


Figure 2.2, EGG wave morphologies in different vocal registers (Source: Mitra, 2004)

In vocal fry/pulse register, double (so-called dichotic) excitations and long closed phases (Baken, 1988; Childers & Larar, 1984 & Kitzing, 1979) can be usually noticed. In chest/modal register, the EGG normally is reported to show a rather rounded closed phase, whereas in falsetto or loft register, the closed phase is normally more pointed, due to the thinning of vocal folds and very short or even insufficient glottal closure (Kitzing, 1982; Roubeau, Chevrie-Muller & Arabia-Guidet, 1987; Schutte & Siedner, 1988) (Figure. 2.3). This distinction is reported to be used to differentiate the falsetto from the operatic head register (Kitzing, 1982). EGG portrays well, the ability of professional singers to balance the transition between different registers without voice breaks/ perturbations. By parameterizing their EGG data, Dejonckere and Lebacq (1990) have revealed the possibility of documenting the regular cyclic variations as a result of vibrato and trillo.

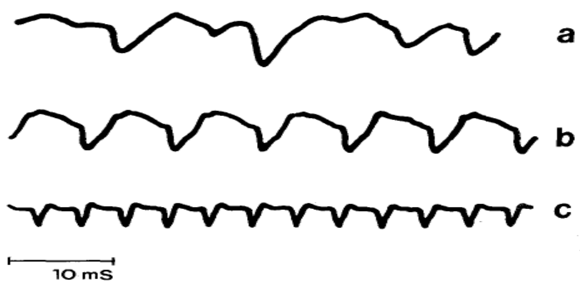


Figure 2.3, EEG waveform at specific registers. (a) Pulse register with dichotic wave configurations and aperiodicity. (b) Modal register, rounded closed phases. (c) Loft register, sharp closed phases. (Source: Kitzing, 1990)

On the basis of EGG studies of around 2,000 clinical phoniatric cases, Sopko (1986) provided qualitative descriptions of typical EGG waveforms for different voice qualities. An elevation in voice intensity was typically believed to cause increased vibratory amplitude in the EGG. In hyperfunctional dysphonia with strained voice quality, the EGG amplitudes were small and often irregular, with prolonged closed phases (Van Michael, 1967). For strained or pressed voice quality, an increased vocal intensity was not found to cause the EGG amplitudes to become larger. In hypofunctional, slack voice quality, the EGG waveform was observed to be flat and sinusoidal at weak intensity. Nevertheless, the author reported that during the assessment of functional dysphonia the amplitude criterion cannot be used for comparison between subjects as EGG amplitude depends on thickness of the soft tissues in neck also. In addition, the peak of maximal contact of vocal folds in the EGG does not essentially signal complete glottal closure. Childers, Hicks and Moore (1990) found certain breathy voices to have EGG waveforms similar to those observed in voices with complete glottal closure.

Klatt and Klatt (1990) reported a stronger perceived breathiness to be linked physiologically to an increased open quotient. This was indirectly measured by Higgins and Saxman (1991) for EGG signal of sustained /a/-vowel. They found decrease in EGG Open Quotient (OQ) values with increasing chronological age for females, whereas the EGG OQ increased for males as speaker's with increased chronological age. The increased OQ values in male voices could be attributed to a consequence of laryngeal changes with increasing age.

Abberton, Howard and Fourcin (1989) reported in one of their tutorials on EGG that breathy voices had elevated OQ values as the open phase in each cycle is extended allowing more air to escape yielding the subjective breathy quality. Mitra (2004) reported that in breathy voices, the contact phase is extremely short, and lower peak amplitude is observed owing to poor contact or incomplete closure of the vocal folds. For individuals with breathy voices, the percentage of closed time of the vocal folds is less than average. This creates the turbulent, aperiodic airflow which is produced for a breathy voice. In contrast, individuals with harsh voices have a higher percentage of closed time, due to hyper adduction of the vocal folds. Aperiodicity of vocal fold vibration is also noticed in cases of harsh voices. Therefore, EGG in this perspective also is a useful objective tool providing confirmation of the clinician's subjective judgments of a client's voice.

Computing the quotients between various segments of the waveform and the entire vibratory period has been a frequent method of creating parameters to be correlated with different qualities of the voice (Hicks, Bae, Childers, & Moore, 1987). In his monograph on EGG, Lecluse (1977) reported a closed quotient of 0.32 in chest register and of 0.12 in the falsetto. These data are in accord with the results of a photoglottographic study by Kitzing and Sonesson (1974), where the open quotient was found to be in the range of 0.63 and 0.77 for low- and high pitched voice, respectively, and 0.83 and 0.70 for weak and strong intensity of voice. An increased open quotient with rising pitch was found in EGG data by Reinsch and Gobsch (1972). Childers, Hicks and Moore (1990) described an interesting criterion, wherein, the closing vocal fold interval was found to decrease with increasing intensity of the voice. This was also reported by Sopko (1983, 1986).

Studying the effect of laryngeal paralysis Hanson, Geratt, Karin and Berke (1988) found the open quotient to distinguish pathological paralytic phonation from normal. However, this was not found to be useful for the separation of different lesions on EGG. Combined photo- and EGG together with videostroboscopy was reported to be useful even for investigating other types of neuromuscular voice impairment (Hanson, 1989).

Olaf Zagolski, (2008) conducted a study to examine the EGG findings in elderly patients with vocal fold palsy. They reported at least one of the following characteristics of EGG waveforms to be observed in patients with vocal fold palsy: prolonged closing phase, shortened opening phase, and prolonged open phase. In the examined elderly participants of their study, closing phase was markedly prolonged due to delay in achieving maximum vocal-fold contact that resulted in elevated values of the closing quotient. This finding was explained by the fact that the healthy vocal fold usually takes longer time to make contact with the paralyzed one. The paralyzed vocal fold is generally in a paramedian position and thereby distant from the midline of the glottis. They concluded that EGG contributes information about the quality and duration of vocal-fold contact in elderly patients with vocal-fold palsy thereby allowing documentation and objective evaluation of consecutive examinations. Figure 2.4, provides an example of an EGG waveform pattern of a case of vocal fold paralysis.

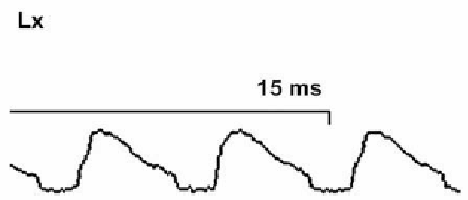


Figure 2.4, An example of EGG waveform recorded in a patient with right vocal palsy. Prolonged closing and opening phase are seen. Duration of vocal fold contact differs between cycles. This waveform shows periodicity but cycles of unequal length, amplitude, and contact irregularity reflecting abnormal vocal cord contact patterns. (Source: Zagolski, 2008)

Van Michael (1967) studied the glottic wave morphology in individuals with vocal fold nodules and observed a notch in the ascending phase corresponding to the adductory portion of the waveform. Similar findings with respect to nodules was reported by Dejonckere and Lebacq (1985) who in their study on EGG in vocal nodule cases reported the contact pattern of vocal folds to be modified and reflected as the presence of a notch in the closing phase of the waveform. They further reported that the S quotient which provides information combining the relative surface and duration of the vocal fold contact during a vibratory cycle is significantly reduced in a few patients with vocal nodules compared to normals.

Altered EGG waveforms and irregular vocal fold vibratory behaviour has been reported in cases of spasmodic dysphonia (Mullerm, Guidet & Pfauwadel, 1987) and stuttering (Borden, Baer, & Kenny, 1985; Muller, 1971; Conture, Rothenberg & Molitor, 1986). Regarding stuttering, the conclusion of Borden et al. (1985) reveal the presence of obvious temporal irregularities in the EGG, such as abnormal voice onset time, repetitions and prolongations that could be owing to improper levels of activity rather than improper timing.

Dejonckere and Lebacq (1983) in their study on diplophonic participants reported the following patterns of EGG waveform to be observed in most cases of Diplophonia.

- Presence of abnormal individual waves (demonstrating rapid upwards deflexion occurring in two phases) (Figure 2.5)

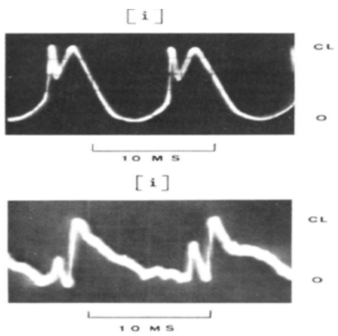


Figure 2.5, EGG waveform demonstrating rapid upwards deflexion occurring in two phases. (Source: Dejonckere & Lebacq, 1983)

- Two different alternating waves (Figure 2.6)

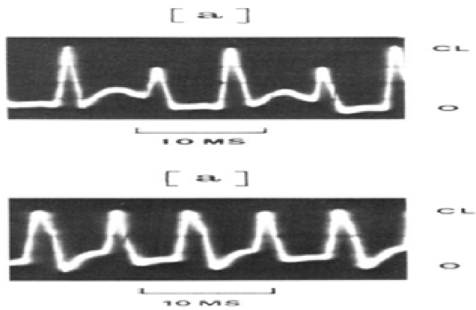


Figure 2.6, EGG waveform showing different alternating waves. (Source: Dejonckere & Lebacq, 1983)

- Repeated groups of waves (Figure 2.7)

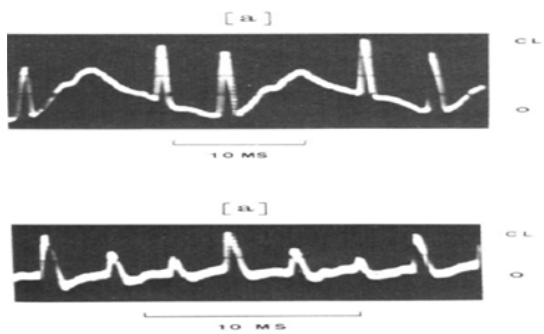


Figure 2.7, EGG waveforms illustrating repeated groups of waves. (Source: Dejonckere & Lebacq, 1983)

Motta, Cesari, Iengo and Motta Jr (1990) explored the pathogonomic traces of EGG waveforms from normals, functional and organic dysphonic patients and reported the incidence of the following patterns.

- In normal subjects, the glottic wave was characterized by a curved peak and more or less uniform inclinations of the ascending and descending portions. (Figure 2.8)

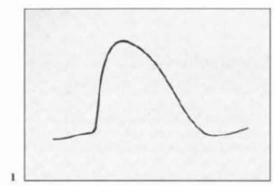


Figure 2.8, Normal EGG waveform. (*Source: Motta et al. 1990*)

- In patients with hypokinetic dysphonia, a particularly sharp peak with reduced amplitude was the reported trade mark morphology. (Figure 2.9)

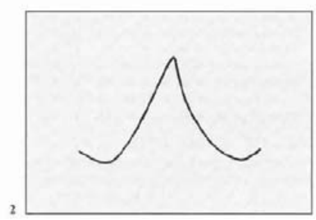


Figure 2.9, EGG waveform in case of Hypokinetic dysphonia (*Source: Motta et al. 1990*)

- In patients with hyperkinetic dysphonia, a plateau like glottic trace was reported. (Figure 2.10)

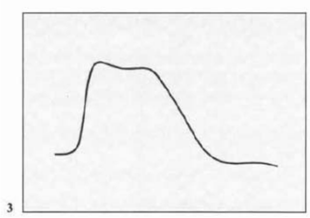


Figure 2.10, EGG waveform in case of hyperkinetic dysphonia. (*Source: Motta et al. 1990*)

- In nodule cases, a single notch responding to the adductory phase was reported in 72% of the patients whereas the remaining 28% were reported to demonstrate the presence of normal wave morphologies. (Figure 2.11)

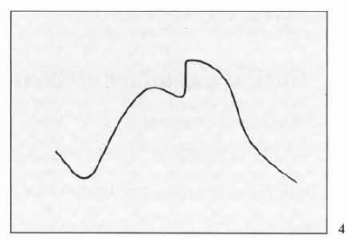


Figure 2.11, EGG waveform pattern in cases of nodules. (*Source: Motta et al. 1990*)

- A single or double notch was reported in a majority of the cases with vocal polyps in the adductory phase of the wave morphology and a normal waveform was also noticed in a minor percentage of the polyp clients. (Figure 2.12)

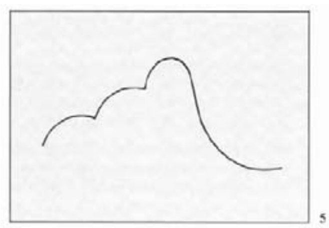


Figure 2.12, EGG waveform pattern in case of polyps. (*Source: Motta et al. 1990*)

- Presence of single notch (24%), double notch (72%) and an irregular wave was evidenced in cases of Reinke's edema.

Lim, Kim and Choi (2009) reported electroglottographs in many cases of pathologic sulcus to be non-existent or weak due to the impaired glottal closure and incomplete compensation. When present, electroglottographs were reported to appear as pit-shaped/ step like undulations during the vocal fold closed phase or as an abrupt slope due to the decrease in the closing phase. A place of pit-shaped fluctuation on EGG signal was observed to depend on the location of sulcus deformity. Figure 2.13 illustrates the various EGG waveform morphologies that were obtained in cases of sulcus vocalis.

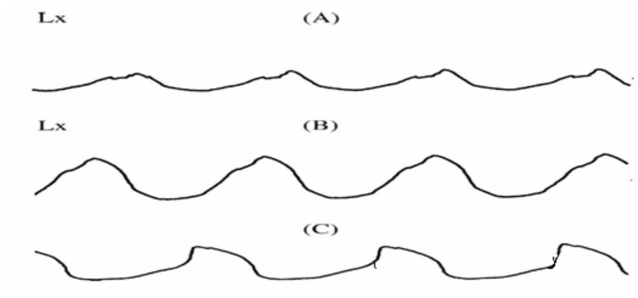


Figure 2.13, Examples of EGG waveform of type III sulcus during vocal fold closure. (A) and (B) pit- shaped undulation during the closed phase. (C) Abrupt slope during closing phase showing decreased closed quotient. (*Source: Lim et al. 2009*)

Motta et al (1990) stated that "Electroglottography can serve to be an incredibly valid tool aiding in the objective evaluation of benign neoplasm's and other laryngeal pathologies in cases specially where examination through invasive and semi invasive procedures are difficult owing to the presence of hyperactive reflexes or the conformation of laryngeal and pharyngeal structures". EGG is a vital device for the comprehensive understanding of the vocal folds physiology and thereby arriving at a diagnosis from its various parameters. Motta et al (1990) further opine that Electroglottography gives the opportunity to choose the most adequate rehabilitative strategy and appreciate the results thus obtained.

Though Electroglottograph has been such an elucidative and much viable instrument to most of the practising SLP's, there are certain pitfalls and limitations of the technique and an all too naive interpretation of the results may prove to be deceptive. Most studies indicate good agreement between apparent vocal fold contact and deflections of the EGG signal with either normal or excised larynges (Fourcin, 1974, Kitzing 1977; Lecluse, Brocaar, & Verschuure, 1975).

2.*5 Limitations of the EGG*

As with the advantages of the EGG, there are certain limitations or shortcomings associated which the researchers using the instrument from several decades have explored.

The present section thus delineates a few of them as put forth in the literature by the pioneers working with EGG. Childers and Krishnamurthy (1985), stated that "EGG remains a poorly understood tracking device, in its present form, not capable of contributing much to clinical diagnosis and treatment of voice disorders".

Kitzing (1990) in his study regarding the clinical applications of EGG reported "the fact that it is usually very easy to obtain, EGG curves may weaken awareness of the limitations of the method and of possible pitfalls during interpretation of its results". Further he reported the following extrinsic variables as being vulnerable yielding faulty results and interpretations.

- The placement of the electrode in front of the thyroid cartilages and the distance between them is crucial (Kitzing, 1990). Further, of equal importance is to lower the skin-electrode electrical resistance by keeping the electrodes clean, lubricated with conductive paste, and firmly attaching to the skin. Especially in female subjects, it may be unfeasible to obtain an exact EGG registration, most often owing to the abundant subcutaneous soft tissue. Another reason for insufficient amplitudes is the generally smaller anatomical dimensions of the female larynx than the male.
- Head movements or vertical shifts of the larynx may induce artefacts during the EGG procedure (Cavallo & Baken, 1985; Baken, 1987).
- Compensating electric filtering and automatic gain control might also introduce distortions to the signal.

Concerning the physiological correlates of EGG functioning, the user should always be aware and cautious about the following facts.

- The EGG does not represent vibrations of the vocal folds as such, but variations in the contact area between them. This too is only an approximation, as the cause of glottographically detected impedance changes still are not known in precisely, nor is the relevance of vocal fold contact area variations to the acoustic voice signal (Kitzing, 1990).

- EGG does not provide exact information about the open and closed periods of vocal folds vibration, as it is not viable to determine the moment of full adduction or abduction. Rather, EGG provides information relative to the degree of vocal fold contact (Kania, Hans, Hartl, Clement, Buchman, & Brasnu, 2006).
- It is also not possible to determine the exact point along the vocal folds where contact is occurring. Hence, a variable like the vertical phase difference of the vocal folds (e.g.: the inferior margin does not move in sync with the superior margin) further complicates EGG data analysis (Colton & Conture, 1990).
- EGG does not provide information about vocal fold vibration during abductory periods (Higgins & Schulte, 2002). Data can also be disturbed by the presence of mucous strands, which can lower the impedance of glottis during open periods and create unexpected fluctuations in the graph (Colton & Conture, 1990).
- Inappropriate placement of the electrodes, excess fat/ excessive sub cutaneous soft tissue in the neck can also deter the signal (Higgins & Schulte, 2002).
- In addition, problems with interpretations of EGG results are compounded in case of disordered speakers; especially if a good signal is not obtained as the model of analysis used with normal speakers may be inappropriate for use with disordered speakers (Colton & Conture, 1990).

2.6. *Sensitivity and specificity of EGG*

Chunsheng, Wei and Xiaoling (1998) examined the effects of Electroglottography (EGG) in screening vocal fold disorders. The authors reported that EGG measurement is sensitive to screen vocal fold disorders, and is specific to distinguish benign and malignant diseases, but not much useful to identify the types or clinical stage of the diseases.

Wei, Wang and Chen (2002) reported the sensitivity, specificity and clinical value of EGG measurement in benign vocal fold diseases. 365 cases of vocal polyp, vocal cyst and vocal leukoplakia pre- and post-microsurgery were measured, and EGG waveform and their parameters were analyzed, respectively. The authors concluded that EGG waveform was sensitive to benign vocal fold diseases to a degree, but the specificity was poor.

Mayes, Menaldi, DeJonckere, Moyer, and Rubin (2008) in their study on "Laryngeal Electroglottography as a Predictor of Laryngeal Electromyography" reported sensitivity and specificity values of EGG. A sensitivity value of 95% and a specificity value of 25% were observed with EGG waveform with evidence by LEMG.

As can be seen from the above mentioned literature, EGG is indisputably the most feasible tool available for most of the practising SLP's to derive at the probable underlying clinical pathological condition. However, owing to certain limitations of the technique, relying exclusively on EGG data for the purpose of deriving at diagnostic markers signalling specific pathological conditions might be deceptive or misleading. Kitzing (1990) states that "some caution against a too uncritical use of the EGG seems appropriate and an all-too-naive interpretation of EGG data may prove detrimental, especially in clinical applications". Abberton and Fourcin (1984) has pointed out that there is no unique relationship between a pathological Electroglottogram and a given anatomical or physiological condition. EGG can provide information regarding period and glottal width irregularities, the source of the irregularity cannot be further evaluated through this method and a visualization technique is essential. Thus, devoid of a visualization tool one cannot assess the vocal folds to determine if there is an indication that the irregularity is due to a change in mass or tension, which is crucial for devising an appropriate treatment plan (Bonilha & Deliyski, 2007). Valuable additional information may be thus obtained by monitoring the vocal fold vibrations, when EGG is used in combination with other methods of investigation such as Videostroboscopy, Photoglottography, and Inverse filtered flow glottography. The present study utilizes videostroboscopy as the visualization instrument and hence, the following section gives a description about the technique and its features.

2.6 *Videostroboscopy*

Stroboscopy is one of the most constructive advents in the field of laryngology that has been of much use to the clinician in comparison to indirect laryngoscopy or laryngeal endoscopy as it consents to the evaluation of more dynamic and discrete aspects of vocal fold vibrations. Stroboscopic examination of vocal folds provides information for a quick and precise diagnosis that is valuable for medical, functional, or surgical treatment, as well as for follow-up (Faure & Muller, 1992). Laryngeal difficulties or voice complaints in a few instances reported by patients are attributable to anomalies of the mucosal wave of vocal folds. Stroboscopic examination permits the assessment of flexibility of the vocal folds movements in greater detail and precision (perfect, moderate, uni- or bilateral, total or partial). Stroboscopy may, at best, help differentiate hyper- and hypofunctional deviations and is evidently useful for follow-up examinations and evaluation of the efficacy of therapy. The technique highlights suspicious phenomena suggestive of latent and hazardous organic pathologies obscured in many overt examinations that could be life threatening or endangering professional decisions. It particularly aids in the early detection and differentiation of superficial or invasive carcinomatous lesions (in which the nonvibrating portions of the vocal folds are significant) in majority of the cases and assists in the subsequent management decisions.

Laryngeal videostroboscopy is used to demonstrate the gradual postoperative changes that occur days to months after removal of polyps, cysts, and Reinke's edema. Hence, it is beneficial to make laryngostroboscopy as an obligatory part of organized outpatient care programs especially for chronic laryngitis patients. By increased utilization of the stroboscope in routine clinical examination, greater information can be acquired about both normal and abnormal vocal production. Either a flexible fiberoptic laryngoscope or rigid laryngoscope can be used for performing videostroboscopy.

As presented by Dr. Wilbur Gould at the 19th Annual Voice Symposium, the rigid stroboscope allows for better analysis of the beneath surface of the vocal cord and immediate subglottic area. Through simple mirror or fiberoptic examination (from above), all of the laryngeal structures may appear normal. When the rigid scope is passed down close to the level of the vocal cords and the angle of visualization is changed, subtle variations can also be noted. Instances of swelling or subglottic polyps may be seen. Change in the angular configuration of the subglottic tissue may be evidenced. All of these may have an effect on vocal production (Gould, 1984).

The judgments based on stroboscopy may reflect different dimensions of voice than that conventional perceptual evaluation provides. Utilization of stroboscopy equipment, with its features of bright illumination, magnification, video and still recording for documentation of vocal fold mobility and position, configuration of glottic closure, and supraglottic compression, for discrete description of vocal fold edges, is remarkably precious. Teaching or educating the patient in terms of explaining the examination results can be best accomplished through the images of stroboscopy. It is a sophisticated method to visualize the vocal fold vibratory characteristics and the adjacent structures. Video documentation using stroboscopy has become one of the essential diagnostic procedure in evaluating the bio-mechanism of vocal fold vibration, laryngeal mucosa, and mucosal vibration and movements (Rosen, Lombard & Murry, 2005). Thus it helps to assess the impact of the pathology on voice production and airway functions. As it is much sensitive in diagnosing subtle laryngeal pathologies, it has evolved as a substantially advanced technology over the rigid or transnasal laryngoscopy. Additionally, stroboscopy has been shown to be critical in the diagnosis of voice disorders, altering the treatment decisions in 14% to 33% of cases typically seen in clinical practice (Sataloff, Speigel & Hawkshaw, 1991; Woo, Colton, Casper & Brewer, 1991)

2.7 *Brief historical synopsis on the materialization of Stroboscopy*

The stroboscopic effect was discovered first in 1829 by Plateau of Brussels and independently by Stampfer of Vienna in 1832 or 1833. It has been utilized to examine vibratory properties of the vocal folds in singers since the 19th century (Woo, Colton, Casper & Brewer, 1992). In 1878 Oertel first observed the larynx of a living human being with the aid of a light that was periodically interrupted by a rotating disk. Through this means he was able to see the vocal folds vibration (Wendler, 1992). The first stroboscopic photographs were produced by Musehold in 1898 and these required multiple exposures owing to the comparatively weak light source. The first mechanical stroboscope, named Stroborama, was assembled by Sequin-Tarneaud; the first electronic stroboscope was built by Cary and Guillet in Paris in 1931. Literature in this purview reveals ample of physicians, technicians, and phoneticians closely associated with the development of stroboscopy. Among the physicians, whose work seems to be greatly influential is Seeman (1921), who applied stroboscopy to study vocal pathology. Fundamental investigations of the physiology of vocal fold vibration, and evaluation of the mucosal wave, were performed by the phonetician Smith in 1954. Most significant engineering accomplishments in stroboscopy were achieved by Timcke (1956), who developed an electronic synchronous stroboscope to meet the special requirements of laryngology. A monograph was produced by Schoenhaerl (1960) that provided the crucial drive in making stroboscopy acceptable in routine clinical laryngology. Fundamental studies by Luchsinger (1967), were a vital prerequisite to practical development of the technique. Wendler proposed Telemicrostroboscopy in 1973. Use of colour televideostroboscopy was reported by Kittel (1977).

2.8 *Principle underlying the stroboscopic technique*

The strobe effect is based on an optical illusion caused by persistence of visual images (Wendler, 1992). The Talbot law says that, images projected on the retina leave after lasting for 0.2 s. Thus, a brief sequence of individual stimuli presented at intervals <0.2 s appear as a continuously moving picture. Rapid periodic motions, such as vibrations or rotations, not typically resolvable by the unaided eye can be made visible by illuminating them with very short flashes of light that are synchronous with the motion of the object under observation. Exact coincidence of the frequency of light flashes and the position of the moving object provide a sharp and clear still picture, because points at the same phase angle of the object's motion are repeatedly illuminated. Slight difference between the frequency of the flashing light source and the frequency of the object's motion produces the well-known slow motion effect (Wendler, 1992).

Modern laryngeal video stroboscopy utilizes a stroboscopic light source, a rigid or flexible endoscope, a low-light video camera, video recorder and a video monitor, all commercially available. Following the above mentioned basic principle of Talbot's law, a stroboscope shines intermittent light flashes on the vocal fold structures. If the frequency of the flashes coincides with the frequency of vocal fold vibration, the vocal folds appear frozen in the phase in which they were illuminated. By varying the timing of the light flashes in relation to the frequency of vocal fold vibration, the vibratory cycle can be illuminated at continually changing points, each successively later (or earlier) in the cycle. The eye perceives the vocal folds as moving in their complete vibratory pattern, but in slow motion. In reality, this image of a single cycle is actually made up of fragments from many cycles (Gelfer & Bultemeyer, 1990).

2.9 ***Prerequisites during the stroboscopic procedure***

As early as 1967, Wendler has stressed the significance of a clear determination of the conditions under which the laryngostroboscopic investigations must be performed. Both the frequency and the intensity of phonation strongly influence the vibratory pattern of the vocal folds. Conditions for successful evaluation of the glottic wave include comfortable phonatory intensity; fundamental frequencies that provide an optimal view of the vocal folds; the vowel /i/ for low frequency phonations; use of the patient's habitual speaking F0. (High frequencies and head voice are associated with low vibratory amplitude and hence must be avoided). Hence, indications of vocal frequency and intensity are an obligatory part of all clinical stroboscopic records (Wendler, 1992). Measuring the frequency is of ease, as it is generally shown by the stroboscopic instrument. Nonetheless, specifying intensity is relatively tricky.

2.10. ***Sensitivity and specificity of videostroboscopy***

Uloza, Vegiene, Pribuisiene and Saferis (2012) determined the sensitivity and specificity of the basic video laryngostroboscopy (VLS) parameters in discriminating healthy and pathological voice classes. The highest sensitivity and specificity separating normal and pathological voice subgroups was revealed for the mucosal wave on affected side. Other VLS parameters presented with high sensitivity in the limits of 84.5–93.9%, whereas the specificity reached 100% for all VLS parameters measured. The authors concluded that VLS is reliable in clinical settings and demonstrates high sensitivity and specificity distinguishing healthy and pathological voice patient groups.

High sensitivity and specificity values of stroboscopy obtained in the present study can be further augmented by the reports of Demerdash, Fawaz, Sabri, Sweed, and Rabie (2015). In their study on sensitivity and specificity of stroboscopy in preoperative differentiation of dysplasia from early glottic carcinoma reported 96.8% sensitivity and 92.8% specificity of stroboscopy with an overall accuracy of 95%.

There are certain other studies too that report high sensitivity values and relatively low specificity values of stroboscopy with respect to organic and functional vocal cord lesions. Wendler, Nawka and Verges (2004) in their report on “Videolaryngostroboscopy and Phonetography” discuss about the sensitivity and specificity aspects of stroboscopy. They report that videostroboscopy is highly sensitive but barely specific in cases of organic dysphonia and little sensitive and not specific in cases of functional dysphonia. They attribute the reason for such a report to the presence of wide variability and inconsistency even in cases of normal vibrations.

WuGuoYing and KeXingXing (2009), in their study on efficacy of videostroboscopy and electro laryngoscope in the diagnosis of vocal cord polyps, reported a sensitivity value of 96 % and specificity value of 66 % for stroboscopy. In this study, the authors concluded that overall sensitivity and specificity of videostroboscopy in diagnosing early vocal cold polyps are much higher than electro laryngoscope. Mehta and Hillman (2012) in their review report on current role of stroboscopy in laryngeal imaging, report that stroboscopy is sensitive to vocal fold vibratory features; nevertheless, the modality lacks specificity exhibited by High speed video endoscopy that is required for adequate judgments.

2.10 *Stroboscopic observations and inferences*

2.10.1 Record forms and their parameters

Clinicians using the stroboscope must be first able to decipher and relate the vibratory pattern to the anatomical configuration and pathophysiology of the disorder. This requires interpreting the stroboscopic recordings relative to normal expectations. Stroboscopy should be viewed as a highly relevant qualitative method. If the stroboscopic method is to be a useful tool for determining “normal” laryngeal behaviour as well as for serving as a diagnostic indicator for laryngeal pathologies, an evaluation protocol is vital, targeting salient aspects of laryngeal behaviour. Ample of researchers have addressed the need for a rating protocol or at least a reporting form for describing and inferring the stroboscopic images. Nevertheless, a universal rating system/scale does not yet exist and evaluation is largely subjective and depends on the skill of the examiner.

As clinical stroboscopic interpretation necessitates standard assessment parameters to be observed and described, a number of authors have put forth certain vital laryngeal and supralaryngeal components and behaviours to be observed and commented. Hirano (1981) recommended observation and description of the following aspects of laryngeal behaviour: (a) fundamental frequency, (b) symmetry of the movements of the two vocal folds, (c) regularity or periodicity of vibration, (d) glottal closure (both in terms of degree and shape), (e) amplitude of horizontal excursion of each vocal fold, (f) portion of each vocal fold that remains immobile during phonation and (g) amplitude of the mucosal wave.

Bless, Hirano and Feder (1987) reported the following stroboscopic features to be observed and inferred: Amplitude of Vibration, Mucosal Wave, Symmetry, Periodicity, Glottic Closure Patterns (Phase of glottic closure, Configuration of glottic closure), and Non-Vibrating Portions and Ventricular vibrations.

Faure and Muller (1992) opine the characteristic phenomena to be observed from the videostroboscopy evaluation to include the vibratory amplitude of the glottic wave, which provides insight into the flexibility of the mucosa and its freedom from the underlying body of the vocal fold. Mucosal flexibility is associated with a clear voice and rich resonance. Specific aspects of importance are amplitude of the opening phase; amplitude of the closing phase; bilateral symmetry of these amplitudes; diminution of the opening phase; diminution of the closing phase; variability with phonatory frequency or intensity; and phase delay of wave activity when comparing the two folds. “Abnormal” strobovideolaryngoscopic findings can occur, and physicians must be aware of the range of vibratory behaviour that may be found in normal subjects (Elias, Sataloff, Rosen, Heuer & Spiegel, 1997).

Messing and Walker (1993) have provided a few vital laryngeal behaviour parameters to be observed and their rating descriptions are as follows:

- Glottic closure patterns (complete, incomplete, bowed, hourglass, anterior gap, posterior gap and/ spindle shaped)
- Amplitude: the extent of vertical/lateral, the extent of lateral displacement from midline (Normal, mild-mod-severely reduced, absent)
- Mucosal wave: The longitudinal flexibility of the fold, seen as a travelling wave on vibration. Absence of mucosal wave described as a “nonvibrating portion” or “adynamic segment”. Rated as Normal, mild-mod-severely reduced, absent.
- Symmetry: Based on the degree to which the two folds appear as mirror images of one another. Rated as Symmetrical, sometimes, mostly, always irregular
- Periodicity: The regularity of successive apparent cycles of vibration. Rated as periodic or aperiodic.

- Phase Closure: Describes the ratio of open to closed phase. Open phase or closed phase predominates and is rated as mostly/ somewhat open or closed.
- Vertical Plane/ Phase Difference: Vocal folds should meet in the same horizontal plane. Rated as Equal, right/ left lower.

Woo, Casper, Griffin, Colton, and Brewer (1995) reported certain signs of vocal fold vibration that need to be visualized and documented during stroboscopy. These include glottal configuration, the amount of opening/closing/closed time (phase closure), phase symmetry, the roughness of the vocal fold edges, mucosal wave propagation, the vibratory characteristics of the folds, and the periodicity of the folds.

Poburka (1999) has developed a 'Stroboscopy Evaluation Rating Form' which consists of 10 parameters listed below.

1. Amplitude: Extent of lateral vocal fold displacement.
2. Mucosal wave: Extent of vocal fold tissue deformation.
3. Vibratory: Presence or absence of vibration in particular locations.
4. Supra-glottic activity: Extent of laryngeal compression.
5. Edge: Ratings of smoothness and straightness.
6. Vertical level: On-plane versus off-plane vocal fold contact.
7. Phase closure: Rating of open/closed phase duration.
8. Phase symmetry: Rating of left-right vibratory phase symmetry.
9. Regularity: Rating of periodicity.
10. Glottal closure: Category describing shape of the glottis at closure.

Echternach, Dippold, Sundberg, Arndt, Zander, Richter (2010) reported 6 parameters to be evaluated in a stroboscopic examination. They are (1) fundamental frequency, (2) periodicity, (3) amplitude (4) symmetry, (5) glottis closure and (6) Mucosal wave.

A stroboscopic report form has been developed by the Voice clinic, All India Institute of Speech and Hearing, Mysore (2013). This report form details most of the vital glottic and supraglottic behaviours. Representation of the report form is presented in Table 2.1.

2.10.2 Stroboscopic findings in distinct vocal pathologies

In a series of 486 examinations, Sataloff et al. (1987) estimated that stroboscopy was precious in the diagnosis and treatment of approximately 1/3rd of the professional voice users in their practice. Bouchayer (1985), in a study of 157 cases of Sulcus Vocalis, mucosal bridges, and vocal cord cysts, stressed the role stroboscopy played in differentiating these lesions from others by visualizing the vocal fold vibratory pattern.

In a study by Woo, Colton, Casper and Brewer (1992), the added value of stroboscopic examination was highlighted in varied vocal pathologies.

- It was found to be most useful in the vocal cord nodule and cyst group, and least useful in the neurologic group.
- Stroboscopy was advantageous in differentiating superficial versus deeply invasive laryngeal carcinomas, resulting in laser cordectomy rather than hemilaryngectomy.
- It proved very efficient in diagnosing mass lesions such as vocal fold cysts and sulcus vocalis that otherwise could be obscured. By documenting the presence of nonvibrating segments and scarring, repeated endoscopy and biopsy was avoided in patients.

- In some hoarse patients without mass lesions, the observation of mucosal wave propagation and amplitude of vibration was critical in the estimation of extent of mucosal edema and vocal fold hygiene status.
- Of note is the high number of vocal fold cysts and sulcus vocalis that were either missed by non stroboscopic means or were misdiagnosed as vocal cord nodules.
- The diagnosis of recurrent vocal cord polyps in a patient who had previous vocal fold surgery was changed after stroboscopy, which revealed poor mucosal propagation over the prior surgery site.
- When vocal fold hygiene was improved in patients with chronic laryngitis and edema, the mucosal wave was found to travel with greater ease across the vocal fold edge, amplitude of vibration increased, and degree of aperiodicity decreased.
- Successive strobe exams helped to determine the timing of biopsies and avoid unnecessary re-biopsies.
- By better visualization of mucosal vibratory behaviour, stroboscopy has contributed to a more secure diagnosis in some tricky management situations.
- Observations regarding mucosal wave presence or absence as well as its propagation proved as a vital factor in reaching a recommendation for medical versus surgical therapy.

Faur and Muller (1992) reported that differential diagnosis of vocal pathologies rests on four criteria namely the flexibility of the glottic wave, glottic shape, and acoustic qualities of voice and history of dysphonia. These authors further reported specific stroboscopic signs associated with specific vocal pathologies as follows.

- Bulging of the free margin of the vocal fold may be associated with stroboscopic evidence of flexibility and a complete disappearance of the bulge during the opening phase; a glottal hourglass shape during phonation; and variations of timbre for certain pitches and intensities.

- Total disappearance of the bulge during the opening phase suggests fusiform edema, or nodules.
- A more translucent bulge not completely disappearing during opening phase is suggestive of pseudo cyst.
- A polyp is characterized by a sufficiently voluminous bulge that may diminish the stroboscopic amplitude.
- A blunt anterior commissure with radiating vascularisation associated with slight glottic gap on phonation, diminished stroboscopic flexibility in anterior- most quarter of the vocal fold to be suggestive of an anterior/sub commissural micro congenital web.
- Malignant tumours often show superficial inflammatory changes or hyperplasia with keratosis or moderate to severe dysplasia. In these cases stroboscopy shows major localized mucosal stiffness, which is a pressing signal for biopsy and further histological evaluation.
- Laryngeal paresis (flaccid) results in a loss of muscle tone of the affected side. This result in decreased stiffness of the vocal fold body, which makes the entire vocal fold, operate mechanically as a single structure because the body is as flaccid as the cover. The vibratory pattern of such a relaxed vocal fold is characterized by wide undulating motions (like the fluttering of a flag) and, by marked reduction or absence of the mucosal wave. Follow-up stroboscopic examination allows precise evaluation of the healing of mucosa, particularly in its depiction of the freedom of mucosal wave.

- Ventricular fold phonation may present with a distinct stroboscopic picture. The ventricular folds may be seen to approximate but not actually vibrate; and they may be seen to adduct and though not approximated show clear signs of vibration; and occasionally may be seen to adduct and interact to produce sound, (hyperphonia).

Woo et al. (1995) studied the stroboscopic signs associated with benign lesions of vocal folds reported the various stroboscopic parameters of glottic closure, amplitude, periodicity of vocal fold vibrations, symmetry etc in 80 patients with diverse benign vocal fold lesions.

- Glottal configuration: A posterior chink configuration was reported to be most prevalent for nodule patients, whereas an irregular configuration was most frequent in the polyp group. An hourglass configuration often expected in patients with nodules was observed in just 31% of that group. A completely closed configuration was observed in both cyst and edema groups.
- Vocal fold edge: Most patients with polyps exhibited more severe edge roughness than other groups. In unilateral polyps, even the unaffected fold exhibited slightly more roughness of vocal fold edges than the other groups.
- Vibratory amplitude: Polyp and edema patients demonstrated severe decrements in vibratory amplitude of the affected fold, and majority of patients in cyst group had moderately decreased vibratory amplitude.
- Mucosal wave: majority of patients in all groups of pathologies had some degree of mucosal wave decrement. Cyst and nodule patients tended to have the least severe mucosal wave propagation change, whereas the polyp group had most severe involvement. Majority of the unaffected folds had normal mucosal wave pattern, barring a few polyp and edema patients who showed mucosal wave abnormalities even in the unaffected fold.

- Vibratory behaviour: Cyst and polyp patients mostly showed partial absence of vibratory behaviour, while a few polyp patients exhibited complete absence of vibration. Edema patients showed slight interruption of vibratory characteristics, a finding that was consistent with the nature of the polyps.
- Vibratory Phase Nodule and polyp patients exhibited predominantly open phase vocal fold vibratory cycles. Edema patients were found to exhibit all four abnormal phase closure characteristics as well as abnormal phase symmetry patterns reflecting differences in stiffness characteristics of vocal folds.
- Periodicity: Most patients in all pathological groups showed regular periodicity, though nodule group had the most regular pattern.

Shohet and colleagues (1996) compared stroboscopic findings between cysts and polyps. They determined that the mucosal wave was the most important parameter in differentiating cysts from polyps. They also found the mucosal wave to be diminished or absent in 100% of vocal fold cysts, and the wave to be present in 80% of polyps.

Elias, Sataloff, Rosen, Heuer and Spiegel (1997) in their study on normal strobovideolaryngoscopic variability in healthy singers reported that small benign masses (cysts, nodules, polyps), as well as vocal fold varicosities can be present without voice complaints evident to the singer. Strobovideolaryngoscopy takes great importance as a follow-up procedure to monitor the status of such lesions and to visualize changes that could be associated with alterations in voice quality. The study also revealed that variations from expected normal laryngeal behaviour could be present even in trained professional singers. Subsequently, in this group of demanding voice professionals, it is extremely essential to obtain baseline assessment of laryngeal function (through stroboscopic evaluation). The authors concluded that it is vital for laryngologists to be aware that normal voice may be present even in cases of "abnormal" laryngeal findings, and to consider this fact before determining causality in individuals with voice complaints.

Kelchner, Stemple, Gerdeman, Borgne, and Adam (1999) reported a few stroboscopic characteristics of vocal fold paralysis to include (1) abnormal vibration with predominant vertical movements, (2) large irregular amplitudes, (3) poor vocal fold closure, (4) asymmetrical vibration, (5) apparent flutter of the affected fold, and (6) absence of edge deflections (upward, on deflected fold).

Thibeault and colleagues (2002) characterized gene expression in vocal polyps compared with Reinke edema. They found evidence of enhanced expression of extracellular matrix proteins in cases of polyps corresponding to increased mucosal wave stiffness as observed on stroboscopy.

Altman (2007), in his study on benign vocal fold masses and their characteristics reports few typical features as evident on stroboscopy and highlights its vitality in diagnosis of these conditions. Table 2.2 and Table 2.3 represent the various characteristics of nodules, polyps, cysts, Intracordal scarring, granulomas, Papilomas and Polypoid corditis as put forth by Altman (2007).

Table 2.2

Characteristics of nodules, polyps and cysts as put forth by Altman (2007)

Nodules	Polyps	Cysts
Bilateral symmetric superficial swelling of vocal folds at the striking zone junction of the anterior to middle thirds. slightly decreased	Smaller polyps: intact mucosal waves and phase asymmetry owing to impaired phase closure and mass effect of the polyp larger polyps:	vocal folds appear asymmetric with occasional evidence of the sub epithelial mass Because of displacement of laminapropria, significantly decreased or absent mucosal

amplitude of mucosal wave, but generally symmetric Decreased phase closure observed owing to the hourglass-shaped glottal closure	prominently decreased mucosal wave amplitude	wave on the side of the cyst evidenced. Phase closure depends on the cyst size and whether there is development of contra lateral reactive callus

Table 2.3

Characteristics of Intracordal scarring, granulomas, Papilomas and Polypoid corditis, polyps and cysts as put forth by Altman (2007)

Intracordal scarring	**Granulomas**	**Papilomas**	**Polypoid corditis**
Markedly reduced/ absent mucosal wave (usually asymmetric), often affecting phase closure.	May appear as solitary or bilobed Often does not affect mucosal wave or phase closure	Decreased mucosal wave noticed	Decreased mucosal wave owing to the mass effect of the edema, often with phase asymmetry An area of focally decreased mucosal wave (at exophytic epithelial wound)

In cases of carcinoma, the epithelial lesion tends to infiltrate into the lamina propria, accounting for the decreased mucosal wave. Also, the fibro vascular fronds seen in Papilomas are generally softer than the exophytic mass produced in carcinoma, so carcinoma would have more of a detrimental effect on phase closure as seen in strobolaryngoscopy.

Palmer, Dietsch and Searl (2012) conducted a study on Endoscopic and Stroboscopic Presentation of the Larynx in Male-to-Female Transsexual (MFT) persons. The purpose of the study was to describe the laryngeal presentation of MFT speakers in their feminine voice. All MFT persons had endoscopic and stroboscopic procedures completed. Images were rated on a range of parameters by two experienced voice therapists to derive the descriptions. MFT participant self-report of voice use/ symptoms and listener identifications of speaker-gender from a perceptual task were procured. The following observations were reported: most MFT persons in this study produced their feminine voice with some type of glottal gap, a posterior chink predominating. Skewing of phase closure relationship towards a higher percent of ‘‘open’’ time also was common. Excess supraglottic constriction was noted for all but one participant. This could point to vocal hyperfunction during feminine voice production being in consonance with the symptoms of vocal fatigue, pain/voice loss from almost all the participants.

2.11. Reports regarding the success of videostroboscopy in otolaryngology practices

There are ample of reports by voice experts using stroboscopy in clinical practice regarding the vital utility of the instrument in diagnostic and therapeutic perspectives. Schwartz (2009) and Sulica and Blitzer (2011) advocated the use of laryngeal stroboscopic assessment in diagnosing general hoarseness and also in specific pathological conditions like organic lesions (Rosen et al., 2012), and vocal fold scarring (Welham et al., 2011).

Cohen, Pitman, Noordzij and Courey (2012) performed a survey of 273 members of the American Academy of Oto-laryngology- Head and Neck Surgery (AAOHNS) and reported 84% of experts implement video stroboscopy. Among the paediatric population too, stroboscopy forms an integral part of voice assessment procedures. Mehta and Hillman (2012) investigated the current role of stroboscopy in laryngeal imaging and reported stroboscopy to be an effective technique in Oto-laryngological practices for both adults and paediatric population.

In the United States, over one million or 6 to 9% of all children experience some form of dysphonia (McMurray, 2003). Hence the usage of stroboscopy as an accurate glottal visualization technique for accurate diagnosis and further intervention has been advocated.

Studies have reported feasibility of stroboscopic examination with the use of flexible (Hartnick, & Zeitels, 2005) and rigid endoscope (Wolf, Fever, Amir & Jedwab, 2005) in the paediatric population. Paediatric laryngostroboscopy is often suggested for comprehensive diagnostic differentiation between benign mucosal lesion and identification of inflammatory processes, especially in children with long-lasting history of dysphonia. Nevertheless, owing to inconsistency in attention span and participation in children, it is often difficult to obtain paediatric phonation samples greater than 2–3 seconds (Mortensen, & Woo, 2008), resulting in reduction in reliability of stroboscopic findings.

Above mentioned studies and reports illustrate in a meticulous manner the efficacy of stroboscopy in diagnosing certain vocal pathologies as well as in delineating the specific vibratory characteristics associated with those conditions. As with other evaluation tools or methods that come with a package of both advantages and limitations, there are certain limitations associated with the stroboscopy too, which the clinician should be aware of.

2.12. Limitations of the stroboscopic method

A fundamental principle in understanding the utility of laryngeal stroboscopy is to be aware of its inherent flaws and then to proceed cautiously further with apt diagnosis based on the instrument’s results. Mentioned below are a few drawbacks associated with the instrument. Wendler, 1992 reports that it is almost not viable to differentiate between normal voices and functional dysphonic voices based on stroboscopic findings alone. The striking slow motion images of vocal fold vibration obtained through stroboscopy are thought to be just an optical illusion. During phonation unlike high-speed imaging of vocal folds, videostroboscopy relies on just sampling segments over many glottal cycles to create smooth video sequences. Vocal folds vibrations with significant aperiodic movements cannot be well gauged with videostroboscopy (Otto, Hapner, Baker & Johns, 2006).

Secondly, contemporary technology provides only a two dimensional view of vocal folds from above. This bird's-eye view restricts the ability to perceive three-dimensional contours of normal as well as pathological tissues (Otto, Hapner, Baker & Johns, 2006). Videostroboscopy is unable to assess the vertical position differences and thickness between vocal folds. Such depth information is vital for determining the exact junction of the vocal folds in the course of phonation.

Additionally, there may be problems evidenced related to the interpretation of examination, including paucity of standard rating forms, poor reliability, and misunderstanding normal variations in vocal fold appearance and motion. Interpretation of the laryngeal videostroboscopy examination has its base on visual perceptual assessment of laryngeal anatomy and physiology. It is vulnerable to interpreter bias, inter- and intra-rater reliability problems, and reliance on level of training/ experience. Nevertheless, there are no standards. Owing to this, false positive as well as false negative errors can surface and due to the lack of standard tools to interpret videostroboscopic examinations communication between practitioners is hampered (Hapner & Johns, 2007). Achieving good inter-judge and intra-judge reliability is critical to the effectiveness of videostroboscopy results. Several studies using a variety of tools have found poor reliability ranging from 31–97% in rating dynamic characteristics of stroboscopic examination (Peppard & Bless, 1990; Bless, Leddy, Rammage & Glaze, 1994).

Bless (1991) noted that failure to consider normal variations can lead to erroneous clinical judgments and over-diagnosis of problems. Distinguishing authoritatively among certain minutely varied sub-epithelial lesions mass lesions (vocal nodules, small cysts, or focal areas of edema/fibrosis) through stroboscopy alone is absolutely tricky. Among the mucosal waves, vibratory amplitudes, and closure adequacy, that are the most relevant features observable by stroboscopy; vibratory abnormalities are poorly demonstrated by the procedure. Objective absolute quantifications are available, but are not always clinically useful. In cases of over-adduction of the ventricular folds and anterior-posterior shortening of the glottis, anterior tilt of the arytenoid segment may occur during phonation and such supraglottal constriction prevents visualization of the vocal folds, especially the vocal process and the posterior glottis. Another problem with the stroboscope is in evaluating the vocal folds in the absence of voice or very low intensity voice. The strobe effect might not be "generated" (Hibi, Bless, Hirano & Yoshida, 1988)

In addition to the above mentioned innate flaws associated with stroboscopy, there are a few practical constraints to the routine use of this instrument in clinical practice especially in developing countries like India. There is a dearth of practising speech pathologists in India who have been trained hands on in performing stroboscopy in clinical settings. In addition, owing to the lavish expenditure involved with the procedure, feasibility of undergoing stroboscopic examinations in routine clinical assessments is hampered.

Notwithstanding, laryngeal stroboscopy contains many inherent weaknesses, including a dependence on regular phonation and minimum requisite phonation time of 2 seconds. Such limitations ultimately confine its universal applicability in the clinical setting, specifically toward patients presenting with irregular phonatory cycles and limited phonatory durations (Mendelsohn, Remacle, Courey, Gerhard & Postma, 2013)

Literature on videostroboscopy portrays it as apparently a vital assessment tool in clinical practice, but certain inherent flaws with the instrument rise speculations regarding its sole considerations in diagnosis. Combined and correlated with other methods of phonatory observation and analysis, stroboscopy clearly adds new dimensions that vehemently enhance and authenticate clinical diagnosis.

2.13. Studies on correlation and synchronization of EGG and stroboscopy with other procedures

Pedersen (1977) reports that when the EGG curves are seen in relation to the stroboscopic examination, evaluation of the relationship and duration of the phases can be performed with greater certainty. Literature reveals numerous studies to be comparing EGG measurements with other measures of glottal function. EGG has been combined with transillumination, acoustic studies, high speed laryngeal photography, and stroboscopic photography, studies of which have attempted to define when closure occurs relative to the EGG signal. In recent years this has led to the combined use of laryngeal waveform information together with laryngeal stroboscopy as well as other methods of glottal function such as the photoglottography (PGG), high speed films, high speed digital imaging (HSDI), videokymography (VKG) etc. However, there is a paucity of information in literature on correlations between data of videolaryngostroboscopic (VLS) examination with that of laryngeal phonatory function assessment using other measurements (Uloza, Vegiene & Saferis, 2012).

Pedersen and Boberg (1973) conducted a study on examination of voice function in patients with recurrent nerve paralysis and reported a rather short closing phase in 10 of 18 patients without paralysis, and in 9 of 20 patients with unilateral paralysis. This corresponded to the stroboscopic findings, which showed poor voice function in many patients without paralysis. Hence, a good harmony between the results of stroboscopy and the electroglottography was reported.

EGG and PGG signals supply information about complementary parts of the glottal cycle- PGG about the open period and EGG regarding the closed period. Rothenberg (1981) reported that the glottis rarely either closes or opens abruptly over its entire length. Rather for part, of the cycle, the folds are possibly in contact or separated over only a part of their length. Thus, EGG and PGG signals likely overlap. Thus Baer et al. (1983) opined that by obtaining both PGG and EGG signals in parallel and observing the overlap, the usefulness of each is enhanced as horizontal phase differences can be detected.

Baer, Lofqvist and Mc Garr (1983) conducted a validation study using transillumination and EGG in collaboration with high speed filming system. Particularly the validity of glottographic techniques specifically PGG and EGG were examined to assess comparable information available in high speed films. Glottographic signals, transillumination and EGG were obtained simultaneously using high speed films. Light from the filming system passing through glottis was sensed by a phototransistor that was placed on the surface of neck and coupled to the skin by a light tight enclosure. EGG signals were obtained from two different equipments having no significant difference between the signals recorded from these two equipments. FM channels of an instrumentation tape recorder with a bandwidth of 2.5 KHZ were used to record all glottographic signals. Through a computer assisted measuring system; frame-frame measurements were made from films during those segments where the film speed was constant at about 4000 frames/sec. Measures of glottal width were done at the widest point along the anterior-posterior dimensions. Figure 2.14 depict the curves (from top-bottom) representing glottal width measurements from PGG, EGG and audio signal.

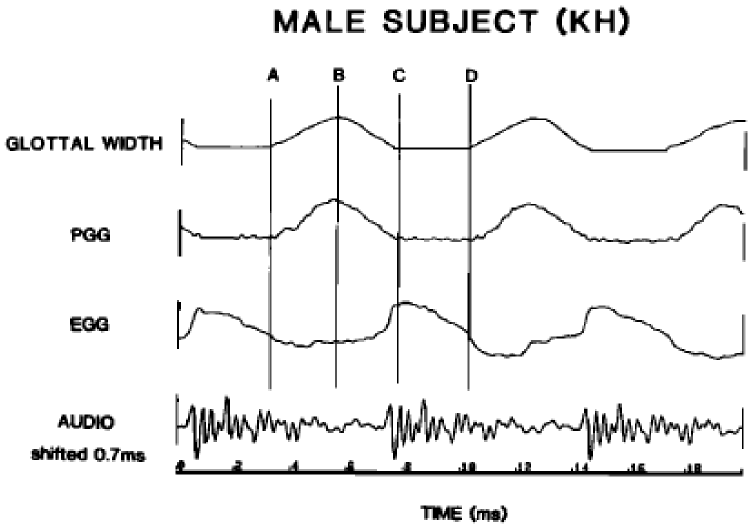


Figure 2.14, Curves representing (from top to bottom) glottal width measured from film, PGG, EGG and audio signal. (*Source: Baer, Lofqvist & Mc Garr 1983*)

Measures of glottal width from the films and transillumination (PGG) were found to be virtually identical. The EGG was corresponding to the other records. Deflection of the EGG signal was noted to occur slightly before the glottis was completely closed as evidenced in film records and PGG signals. The descent of EGG was seen to get more rapid at the moment of glottal opening, producing a knee in the curve. The correspondence of the EGG signal with other measures of glottal activity confirms its validity as an indicator of vocal fold contact. The rate of EGG signal deflection just prior to the maximum closure is very sharp, and occurs over an interval comparable to the interval between film frames. This aspect of EGG signal agrees with the understanding that glottal closure is rather abrupt and demonstrates minute horizontal phase differences. The EGG signal is also consistent with the notion that glottal opening is more gradual in both vertical and horizontal differences. The authors conclude that therefore the simultaneous photo and EGG signals can be used as advantageous in studies of voice production for monitoring the laryngeal vibrations patterns.

Anastaplo and Karnell (1988) made the first step towards the routine clinical use of synchronization so that both synchronisation and wave shape could emerge from a Laryngographic signal source. A logical extension of this approach was to use a clinical desktop computer to control the stroboscope on the basis of laryngeal period-period closure information. The advantages of this were: the instant of illumination of the vibrating vocal folds could be automatically adjusted to obtain an exact sequence of stroboscopic light pulses that could scan through successive periods, providing precise vocal fold images for immediate and subsequent examination. Second, a longstanding objection to stroboscopy could be avoided by the use of these precisely defined single light flashes each uniquely linked both to single image and to a defined point on the reference laryngeal waveform. Pathological voices that are temporally irregular have erratic periodicity that makes it impracticable with ordinary stroboscopy to freeze a picture at one point in the vibratory cycle and to adequately interpret sequence of images. By associating each single image with its corresponding EGG waveform general stroboscopic ambiguities could be avoidable.

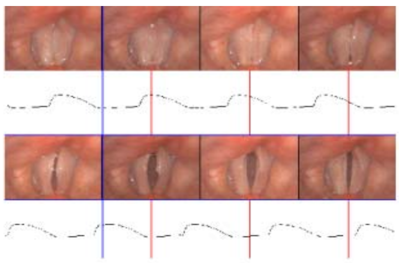


Figure 2.15, Synchronized EGG and sttroboscopic recordings of modal phonation. (*Source: Anastaplo & Karnell, 1988*)

This was examined in different vocal registers and qualities by the authors. The following section provides a brief account of their synchronization results. In modal voice (Figure 2.15), the initial closure of vocal folds, a sharp rise in the laryngeal waveform was well depicted. Closed phase was also well explained and the interval of contact between the vocal folds was found to isolate the supra-glottal resonances from sub-glottal effects.

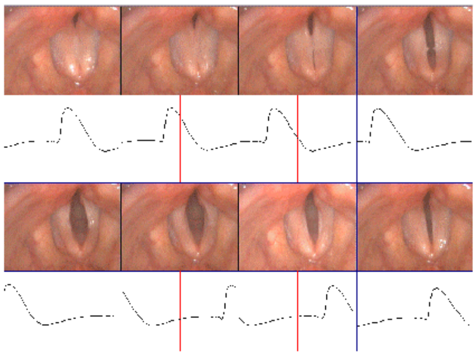


Figure 2.16, Synchronized EGG and sttroboscopic recordings of breathy phonation.
(Source: Anastaplo & Karnell, 1988)

The breathy voice quality shown in Figure 2.16 was characterised primarily by the longer open phase. During the open phase the supra-glottal vocal tract is coupled to the sub-glottis and, as a result, its resonances are more damped compared to modal voice. Vocal tract resonances are also less well defined in amplitude as this voice quality is associated with a less rapid closing phase. An additional aspect of breathy voice is that it is associated with a frictional quality emerging from glottal tumultuous air flow excitation. Although laryngeal movement is periodic it gives an auditory perceptible component of irregularity to the speech waveform from period-period which can just be seen in the open phase intervals of the speech waveform.

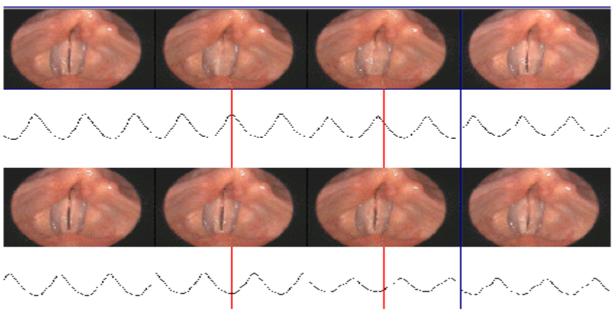


*Figure 2.17***,** Synchronized EGG and sttroboscopic recordings of falsetto phonation.
(Source: Anastaplo & Karnell, 1988)

The falsetto voice quality images and the speech and Lx waveforms (Figure 2.17) show the main features of this phonation type by the length, and extension, of vibrating vocal folds, lack of mucosal waves on their surfaces and the rather sinusoidal laryngeal wave shape. This phonation type is also featured by near sinusoidal ease of vocal fold motion.

Anastaplo and Karnell (1988) conducted a study wherein, EGG was combined with synchronized videostroboscopy in split-screen images to correlate surface configuration of vocal folds with EGG waveforms representing vocal fold contact area. They reported that opening along the superior margin of the glottis usually coincides with the knee observed during opening phase of the EGG waveform (Fourcin, 1981; Rothenberg, 1981; Childers and Krishnamurthy, 1985). In this study, the knee was recognized through visual inspection of the undifferentiated EGG waveform. Although measurement reliability was satisfactory the data demonstrated considerable inconsistency. This variability was evident in the EGG wave shape as well as in the videostroboscopy image.

Trapp and Burke (1988) studied the correlation of photoglottography and electroglottography with VLS in an in vivo canine model. They noted that the PGG and EGG waveforms were distinctly different between the simulated unilateral recurrent nerve paralysis and the superior laryngeal nerve paralysis. The authors concluded that PGG and EGG waveforms correlated with videostroboscopy in an invivo canine model of phonation with simulated unilateral recurrent or superior laryngeal nerve paralysis.

Hanson, Gerratt, Karin and Berke (1988) conducted a study on “Glottographic measures of vocal fold vibration: an examination of laryngeal paralysis”. In this study PGG and EGG were applied to group of patients with recurrent laryngeal nerve paralysis, superior laryngeal paralysis and combined recurrent and superior laryngeal nerve paralysis. The authors found that the PGG wave shapes differentiated better between different categories of paralysis. It was concluded that EGG appeared to be less useful than PGG.

Hill, Meyers, and Scherer (1988) conducted a study to compare the success of four clinical techniques for voice analysis: videolaryngoscopy, videolaryngostroboscopy (VLS), electroglottography (EGG) for laryngeal adduction, and acoustic perturbation analysis. A computer program developed by Titze (1984) called the GLIMPES (Glottal Imaging by Processing External Signals) to analyze EGG recordings to predict laryngeal configuration and dynamic vocal fold motion was incorporated in their study. A laryngeal abduction measure was also obtained from that analysis. A number of perturbation analyses on recorded signals were also performed through GLIMPES. Results of this study suggest that the EGG signal is not useful when the voice is much aperiodic, an obvious conclusion, but often can be meaningfully interpreted by visual inspection of wave shape when the software analysis is unsatisfactory. Nevertheless, the acoustic measures were not easily compared/correlated to the VLS judgments. Majority of patients with even abnormal acoustic indices showed normal appearing periodicity and amplitude on VLS. The authors conclude that this could be due to the effectively low visual sampling of vibration inherent to stroboscopy. This suggests that stroboscopy should be supplemented by more accurate perturbation measures in order to determine laryngeal stability. The study further demonstrates that VLS, EGG analysis, and acoustic measures are useful and complementary clinical tools to evaluate laryngeal function. The authors concluded that clinical readiness for all of them would allow for more complete voice analysis for clinical purposes and for meaningful information gathering if one of the techniques were to be inappropriate/fail owing to specific patient conditions.

These authors further conducted a study in 1990 on similar lines taking two normal and 26 consecutive voice patients. VLS was performed first and the authors subjectively scored the videotapes of the exams. Following this EGG and later acoustic recordings were made. A report form with perturbation measures (from the acoustic signal) and abduction measures (from the EGG signal) as well as a subjective analysis of both acoustic and EGG measures and waveforms were done. The EGG signal was analyzed using an analysis synthesis scheme (GLIMPES). The abduction quotient (Qa) was obtained for five consecutive cycles within approximately the centre position of each token. This parameter would increase depending on whether vocal process separation increased or vocal fold amplitude decreased.

Excised canine larynx and human studies verify abduction quotient (Qa) as a useful measure of glottal abduction. Values of Qa < -1.0 are suggestive of hyper adduction and > 0.5 suggest hypo adduction. An additional method of judging laryngeal adduction rigorously by viewing of EGG wave shape was also carried out. All four techniques were successful for 11 of the 26 patients (42%), indicating a wide range of diagnoses. Both the videostroboscopic view of the larynx and analysis of the EGG signal allowed for a judgment of laryngeal adduction. A correspondence between the visual judgment of adduction through VLS and decisions based on EGG analysis was obtained. Eleven of the 16 cases were in essential agreement. One of the two cases of hyper adduction showed through VLS that the larynx "appeared tight" despite an anterior chink, suggesting that the larynx may have been hyper adducted at the vocal processes, a constitution reflected in the EGG examination too. These results suggest that there appears to be a vital correspondence between adduction seen via stroboscopy and inferred through the EGG. Both techniques appeared to be diagnostically valuable. The overlap of information between the visual techniques and the quantitative techniques is of primary value when one or the other is not feasible to obtain for a patient. The authors concluded that there was a moderate correspondence between VLS and EGG analysis for the estimation of glottal adduction.

Karnell (1989) opined that valid interpretation of the EGG waveform necessitates comparison of the waveform with other measures of glottal function. Techniques that have been incorporated mostly include high speed laryngeal photography and stroboscopic photography. Roch, Comte, Eyraud and Dubreuil (1990) reported synchronization to be an original process of combining laryngeal EGG and stroboscopy in an extremely precise manner. In their study, they aimed for advantages of obtaining qualitative phonatory information at a threefold process. These are:

(1) It aids the phoniatrician to achieve a better understanding of the EGG curve, to observe the manner in which vocal cords open and close during vibration, to measure real time of closure and opening and to investigate if there is contact, in cases where stroboscopy is doubtful.

(2) It helps the phoniatrician to achieve better understanding of intralaryngeal behaviour during phonation, as stroboscopy gives a vertical observation from above, whereas EGG is transverse and perpendicular. This obliges the observer to make a three-dimensional synthesis which is entirely volumetric, thus completing the two-dimensional image provided by stroboscopy.

(3) The process corrects the principal flaw in stroboscopy, which evens out irregularities and shows rapid and supposedly stable mean movement. The EGG gives a description of each vibratory cycle.

Further, in the results of their study, they put forth in a clear manner a few vital attributes of vocal fold closure and opening. They reported that when the EGG curve rises this corresponds to an increase in the area of contact between the vocal cords. At the peak of this curve, this area of contact is therefore at its maximum and opening begins as the EGG curve falls. Figure 2.18, represents synchronized EGG and stroboscopic recording showing closing motion upwards and opening downwards. The arrow indicates the exact moment of flash during vibration

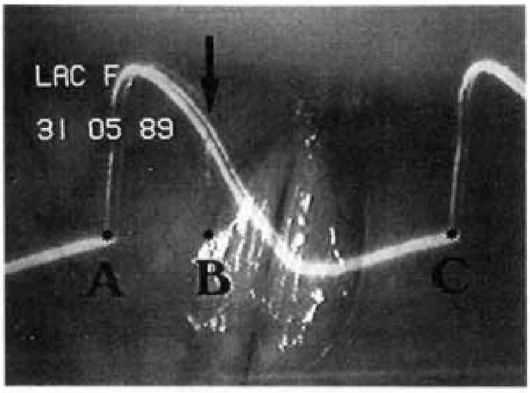


Figure 2.18, Synchronized EGG and stroboscopic recording showing closing motion upwards and opening downwards. The arrow indicates the exact moment of flash during vibration. (*Source: Roch et al. 1990)*

Consequently the higher the frequency, the more difficult it is to detect brief anomalies, irregularities and accidental details; the EGG will make up for this inadequacy. Additionally, in cases where complete contact does or does not occur between the cords, the EGG is far more accurate than stroboscopy. This is illustrated in the Figure 2.19. The authors report that a healthy voice shows great regularity in both the stroboscopy and EGG. A pathological voice (for example a polyp) shows great instability on the EGG which the stroboscopy obscures.

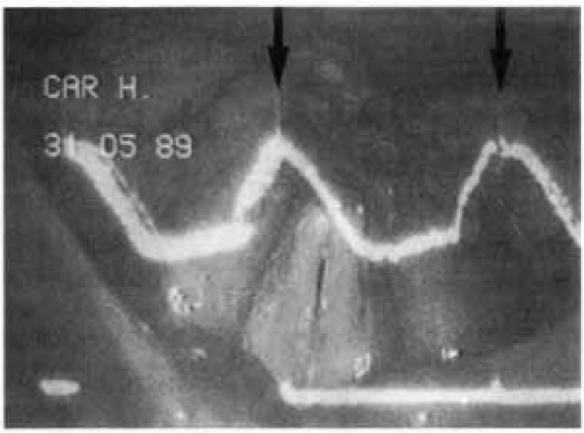
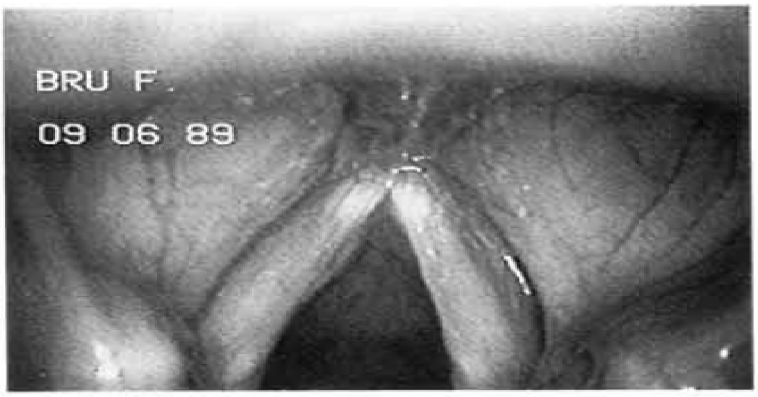


Figure 2.19, Synchronized EGG and stroboscopy picture that shows abnormality detected on EGG waveform being obscured in stroboscopy. (*Source: Roch et al. 1990)*

The authors report of another case where anterior sub glottal nodosity of the left vocal cord is present. The patient is reported to have undergone surgery two weeks before the examination for a subcordal Papilomas on the left side. The stroboscopic examination alone suggests that the raising has no effect on the sound: the contact is regular, the amplitude of vibrations is normal and the mucous membrane of the free edge and the upper face is relatively supple. The EGG shows a wave which is sometimes very wide and which sometimes divides into two, with intermediate forms combining these two aspects. The marker in Figure 2.20 indicates that the contact area is at its greatest when a slight insufficiency of the anterior closure is apparent. In the adjoining figure (Figure 2.21) the closure seems to be total even though the contact area is considerably less. The authors suppose that opening has already started at a lower level, and the excess amplitude of the first peak is due to the raising observed. Here again, when the intensity is weak, the aspect of the double peak disappears, showing that the raising does not have a constant effect in functional terms.



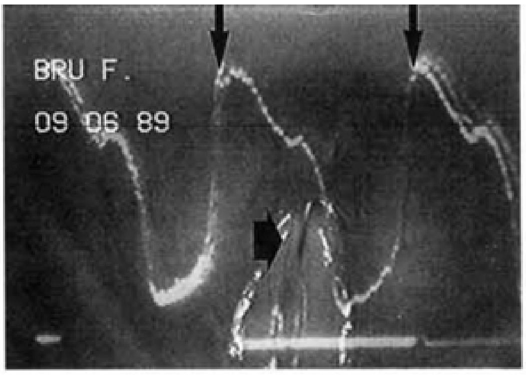


Figure 2.20, Synchronized stroboscopic and EGG recording showing closing and opening instants. Contact is maximum on the first peak; slight insufficiency of closure is seen at the anterior part of stroboscopic picture (arrow). (*Source: Roch et al. 1990)*

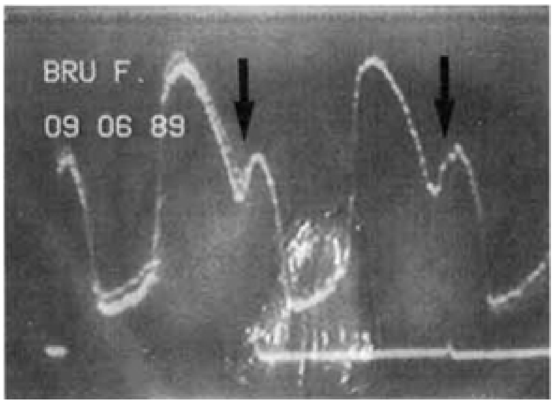


Figure 2.21, In the second peak, the contact is less but the stroboscopic closure seems to be more complete. (*Source: Roch et al. 1990)*

Karnell, Li and Panje (1991) conducted a study to evaluate the length of glottal opening in patients with vocal fold tissue changes using synchronized videostroboscopy and electroglottography. Subjects constituted four groups of patients; two with no clinically significant voice disorder, one with vocal fold polyps, and one with vocal fold nodules. Measurements of open glottal anterior-to-posterior length were obtained from the video records. For each subject, ten cycles of simultaneous videostroboscopic and EGG recordings of vocal fold vibration were measured. Cycles were identified by inspection of the videotape records and segments containing stable vibratory segments were selected. Certain EGG waveform markings of specific events were made: maximum glottal opening (A); baseline *offset,* the major upward deflection of the waveform associated with beginning of vocal fold contact (B); the point of *peak* waveform amplitude associated with maximum vocal fold contact (C); and baseline *onset,* the point where the waveform returns to baseline associated with the termination of vocal fold contact (D).

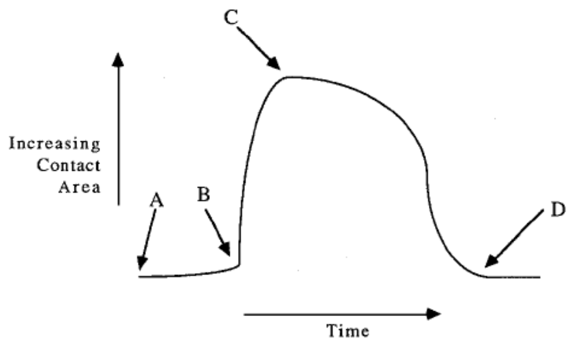


Figure 2.22, The points on the EGG waveform where anterior-posterior open glottal length measurements were obtained. A: Maximum glottal opening. B: EGG baseline offset. C: EGG peak. D: EGG baseline onset. *(Source: Karnell et al. 1991)*

The open glottal length measurements from points B (offset), C (peak), and D (onset) were normalized to the maximum open glottal length measurement. Identification of EGG events (baseline offset, peak, baseline onset) was accomplished by visual identification of these events on the videotape records. In this study, mean relative anterior posterior (A-P) length of glottal opening was found to be smaller at the time of EGG waveform baseline offset (signalling beginning of vocal fold contact) and at the EGG waveform baseline onset (signalling termination of vocal fold contact). Smaller length of glottal opening reflects an increased length of vocal fold contact and, consequently, increased glottal closure. Mean relative length of glottal opening for the group with vocal fold polyps was similar to that for the group with nodules at the waveform baseline offset. The two groups differed at the time of waveform baseline onset, with the nodules group exhibiting lower mean relative glottal opening. The two groups with no observable vocal fold pathology were not significantly different at the waveform baseline offset, but those groups did differ at the waveform baseline onset. No differences were found among the groups compared at the time of maximum vocal fold contact as reflected by peak EGG waveform output. This finding was distinguishing as it seemed reasonable that if vocal fold neoplasms exhibit effect of reducing glottal closure, that effect would be most noticeable at the time of maximum glottal closure. The results indicate that vocal fold neoplasms may have the effect of contributing to glottal closure, rather than inhibiting glottal closure as previously reported.

The data indicate that patients who present with complaints of vocal disturbance, but show no abnormality upon examination, may be discriminated from normal individuals by an increased glottal closure (decrease in mean relative glottal opening length) at the termination of vocal fold contact (EGG waveform baseline onset). The consolidated findings of the study support the conclusion that vocal fold pathology may be best identified during closing or opening phases of the vibratory cycle, rather than during the closed phase. It is also reported that the nodules tend to contact one another more quickly at the beginning of closing phase and separate more slowly at the end of opening phase compared to surrounding tissue, resulting in the hourglass shaped glottal configuration.

Hertegird and Gauffin (1995) conducted a study to examine the relationship between variations in glottal area and vibratory patterns during phonation studied with stroboscopy and glottographic methods. Two normal male and three female subjects were examined by means of simultaneous stroboscopy, flow glottography, and electroglottography. The results revealed several glottographic parameters for male phonations to be highly correlated with the measurements of glottal insufficiency and also to differ significantly between normal, pressed, and breathy hypofunctional modes of phonation. The EGG waveform was also strongly related to the measured glottal insufficiency. This further corroborates the assumptions made by Rothenberg and Mahshie (1988).

Hess and Ludwigs (2000) conducted a study to determine if laryngeal transillumination in combination with stroboscopy (strobophotoglottography; SPGG) is useful for (1) the visualization of vocal fold vibration (VFV) opening patterns, (2) the localization of initial vocal fold opening in horizontal glottal thirds (anterior, midmembranous, and posterior), (3) determination of the temporal correspondence of Electroglottography (EGG)- knee and initial vocal fold separation, and, (4) automatized quantitative measurements of glottal area function within endoscopic images.

Combined presentation of EGG signal and stroboscopic images on one monitor was considered helpful and hence was incorporated in their study. EGG waveforms were obtained with a custom EGG device (Laryngograph TM, England). Stroboscopic light flashes were marked on a flat analog signal displayed in parallel to the EGG signal. The compound image was displayed on a control monitor. Breathy, normal, and pressed voice resulted in posterior-to-anterior opening, midmembranous opening, and anterior-to-posterior opening patterns, respectively. In the range of normal voice types, simultaneous opening patterns of all three horizontal portions of the glottis were also seen. In some cases, zipperlike openings (posterior-to-anterior) and simultaneous openings seemed on minimal differences in vocal process approximations (adductions), where slightly more abducted vocal fold configurations more frequently leaded to zipper like openings.

In the EGG signal, the visualized inferior glottis opening co varied with the EGG-knee, (the “bump”), where the signal amplitude begins to decrease more rapidly. The precise timing of these events was achievable with the technique of marking strobe flashes in a paralleled analog signal displayed together with the EGG signal. The EGG knee indicated the very first moment of inferior vocal fold separation, which was seen by spatial increase of transilluminated light energy in the glottis plane seen in video images. The presence of vocal fold separation at this point, reflected in the EGG-knee, is in consonance with the understanding of the EGG to represent degree of vocal fold contact over time. Hence, their study highlighted the importance and significance of combining two efficient vocal measurement and visualization techniques.

Sercarz, Berke, Gerratt, Kreiman, Ming and Natividad (2002) conducted a study on synchronizing videostroboscopic images of human laryngeal vibration with physiological signals. They reported a new system that permitted correlation of videostroboscopic images with corresponding physiological measures, such as glottography and subglottic pressure. A healthy volunteer who had induced unilateral vocal cord paralysis (by infiltrating local anaesthesia into the recurrent and superior laryngeal nerve) was the subject. Vocal-fold vibrations were monitored by photoglottography (PGG) and Electroglottography (EGG). Analog signals from the EGG and PGG were synchronized with the video and correlated. Images were sampled throughout sustained phonation. This technique provided for study of events during glottic vibration. Results obtained were found to be in close agreement with previous studies that correlated the vocal-fold morphology to glottographic signal using other methods. The main disadvantage of this method was related to the limitations of stroboscopy. Figure 2.23 provides a brief elucidation of the procedure that was employed.

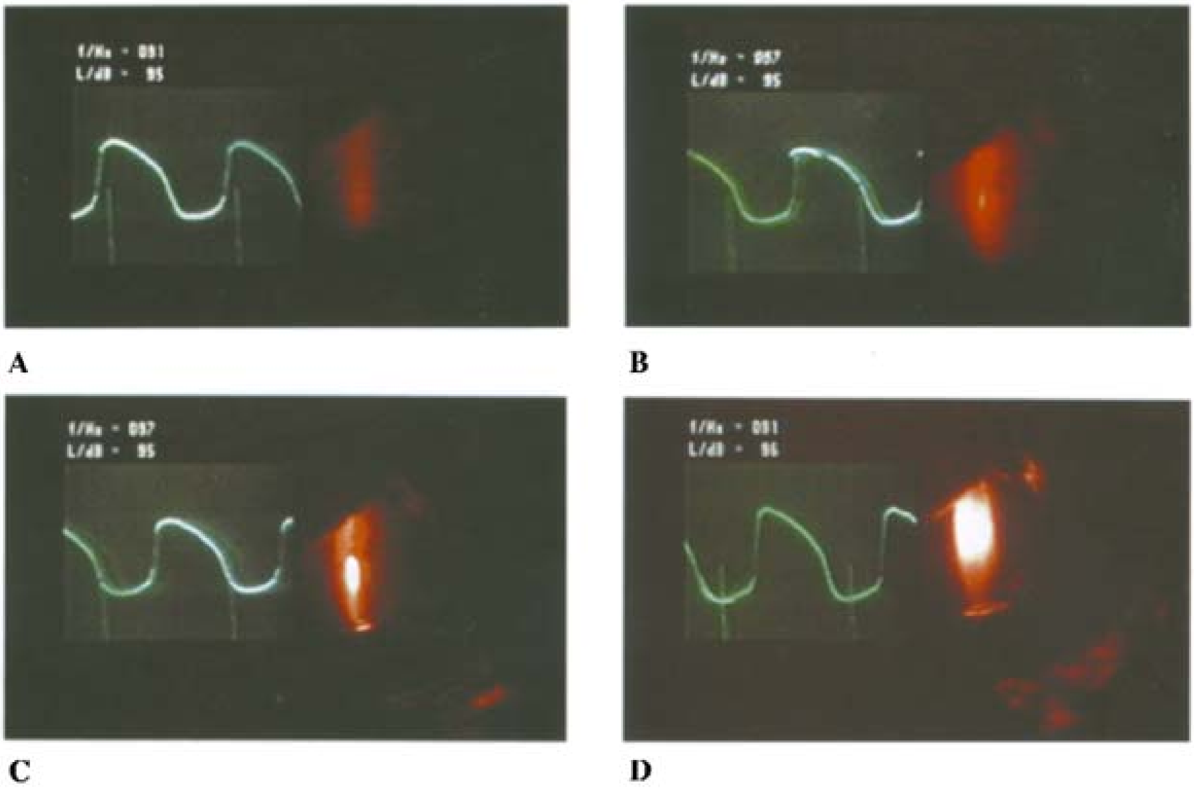


Figure 2.23, Four images taken with the trans-vocal fold transillumination (Source: Sercarzet al. 2002)

Shaw and Deliyski (2006) conducted a study to preliminarily ascertain the variation in mucosal wave magnitude and symmetry for normophonic speakers as assessed via standard and novel techniques (stroboscopy, high-speed video endoscopy (HSV) playback, mucosal wave (MW) playback, and mucosal wave kymography (MKG) playback) and compare findings across modal and pressed phonations. The authors report that a typical mucosal wave, as viewed through stroboscopy, should travel one-half of the width of the superior surface of the vocal fold during modal phonation. In this study, F0 of the participants was measured for comparison of the influence of F0 on visibility of the mucosal wave. F0 had a moderate to marked degree of correlation with judgments of magnitude from HSV playback, a moderate degree of correlation with magnitude ratings from MW playback, and a low degree of correlation with ratings from MKG playback and stroboscopy. Ratings of mucosal wave presence during habitual phonation were highest from stroboscopy, not HSV or HSV derived playbacks as was expected. Approximately, twice the number of samples was rated as having typical mucosal wave from stroboscopy than from HSV. This finding suggested that norm for stroboscopy need not apply to HSV. The degree of mucosal wave asymmetries was rated more severely and accurately through stroboscopy, with less than 30% comprising mild asymmetries.

Olthoff, Woywod, and Kruse (2007) reported the competency of High Speed Imaging (HSI) and stroboscopy. They noted that while HSI was more reliable and less prone to interpretive variances than stroboscopy, their comparative study was unable to demonstrate any specific clinical scenarios in which HSI is clearly indicated. Mortensen and Woo (2008) described a single case report in which HSI in comparison to stroboscopy did change the clinical course of a dysphonia patient. Using HSI, a new finding of unilateral mucosal wave asymmetry was seen which was not found on stroboscopy.

Krausert, Olszewski, Taylor, McMurray, Dailey and Jiang (2011) conducted a study to discuss the benefits, disadvantages and clinical applicability of different mucosal wave measurement techniques, such as electroglottography, photoglottography, ultrasound and visualization techniques including videokymography, stroboscopy, and high-speed digital imaging. In this study, the authors further report advantages and limitations of EGG and stroboscopy when done in isolation and in synchronization in analysing mucosal wave and other voice parameters. When synchronized with videostroboscopy in normal speakers, EGG was observed to detect the onset of glottal opening along the inferior surface of vocal folds, which otherwise would be unseen on visualization techniques, being covered by the upper vocal fold. When used with high-speed imaging and acoustic analysis, EGG was found to analyze irregular vibratory patterns, demonstrating its clinical applicability in analysing pathological voice. The authors note that although EGG waveforms are unaffected by other activity in vocal tract or environmental noise, they may be difficult to accurately interpret, as the waveforms are vulnerable to normal variations like mucous string across the glottis. EGG and PGG do not have the ability to distinguish between the left and right vocal folds, rendering both unable to determine the direct cause of an irregularity. The authors opine that when used alone, indirect imaging techniques are not as useful for quantifying mucosal wave parameters as visualization techniques. Nevertheless, they often provide additional information when used in conjunction with visualization techniques. In this manner, indirect imaging techniques can enhance understanding of the mucosal wave.

Considering the efficacy of stroboscopy, the authors report that when comparing the accuracy of the two methods (stroboscopy and HSDI) for visualizing periodic vibrations, no significant differences were found. However, when voice disorders were studied, (especially those with aperiodic voices), HSDI proved to be significantly more accurate and interpretable than stroboscopy. Furthermore, HSDI allowed for observation of phase asymmetry when stroboscopy did not. The authors opine that although qualitative differences have been found between results of HSDI and stroboscopy, such assessments are susceptible to inaccuracy. The authors (Krausert, Olszewski, Taylor, McMurray, Dailey & Jiang, 2011) conclude that a quantitative comparison of HSDI and stroboscopy may also further elucidate differences between them.

Dollinger, Dubrovskiy and Patel (2012) report High Speed Digital Imaging (HSDI) to be a better glottal visualization measure as compared to stroboscopy. Unlike stroboscopy, HSDI offers a means for directly measuring spatiotemporal characteristics of vocal fold vibrations by recording actual cycle-to-cycle vibratory motion with superior temporal resolution of up to 4,000 frames/ second. This level of detail is especially critical for comprehensive clinical appraisal of children's voices which have a higher habitual F0 and shorter phonation duration during endoscopic imaging, compared to adults.

Uloza, Vegiene and Saferis (2012) conducted a study to evaluate the correlations among the basic video laryngostroboscopic (VLS) parameters and vocal function assessed using a multidimensional set of perceptive, acoustic, aerodynamic, and subjective voice measurements. Digital VLS recordings and multidimensional voice assessments were performed for 108 individuals (26 healthy and 82 patients with mass lesions of vocal folds and paralysis). The VLS variables (glottal closure, regularity, mucosal wave on the affected/healthy side, symmetry of vibration, and symmetry of image) were rated and quantified on a visual analog scale. Correlations among the VLS parameters and results of acoustic voice analysis and voice range profile (VRP), data of subjective (voice handicap index [VHI] and glottal function index [GFI]), perceptual (G-grade, R-roughness, B-breathiness, A-asthenic scale), and dysphonia severity index (DSI) measurements were tested using Pearson's correlation coefficient. The authors concluded that although VLS does not show the fine details of each vibratory cycle, it allows for the estimation of a vibratory pattern averaged over many successive cycles. This could provide real time information about abnormal vocal fold vibration. Hence, in clinical settings, VLS is considered to be the gold standard in determining the pathological changes and the vibratory mode of vocal folds. This study presents the first comprehensive attempt at defining relationships between measures derived from VLS assessment of vocal fold vibration and perceptual, subjective to instrumental assessments of the patients' voices. The major finding of this study was that, the parameters obtained through different modalities (VLS, acoustic voice analysis, perceptual and subjective voice evaluation, and VRP) showed significant correlations with quantitative VLS measurements. This could be anticipated as each of the modalities measure different aspects of voice production, and therefore together represent complementary measurements.

Mendelsohn, Remacle, Courey, Gerhard and Postma (2013) conducted an exploratory study to compare and identify specific laryngeal pathologic states in which High Speed Imaging (HSI) could improve the diagnostic yield above that of videostroboscopy. In the study, HSI was applied to more clearly visualize mucosal wave mechanics. By capturing a minimum of 2000 images/second, HSI captures at least 10–20 frames per vibratory cycle depending on the fundamental frequency. By capturing multiple frames within each cycle, HSI is independent of periodic vibratory motion and can describe vibratory behaviour beyond what is possible with videostroboscopy, thereby overcoming its limitations.

In this study, 28 unique patients were made to undergo videostroboscopy and HSI examinations with each patient providing two laryngeal examinations. Raters were presented with a list of 10 clinical diagnoses and were asked to choose a single best diagnosis for each examination. Four academic laryngologists, each with a minimum of 15 years clinical experience, were asked to perform the video interpretations. The results revealed that the overall diagnostic concordance between stroboscopy and HSI was 41.1%. Across all raters, the diagnostic correlation between the two techniques was a fair level of agreement without statistical significance. This study was an attempt to explore the clinical scenarios in which HSI was speculated to improve the diagnostic potential beyond the limitations of stroboscopy. HSI demonstrated significant and meaningful interrater correlations for specific diagnostic categories, including vocal fold polyps and presbyphonia.

- Using stroboscopy, significant correlations were demonstrated with vocal fold polyps, cysts, and nodules. This finding correlates to previous reports demonstrating reliable stroboscopic evaluation of sub epithelial lesions without benefit from HSI.

- Though vocal fold polyps were reliably diagnosed using HSI in the study, the magnitude of correlation was greater using stroboscopy, and the data do not favour the indication of HSI to improve the diagnostic capacity of polyps.
- The study identified presbyphonia as a clinical pathology in which the diagnostic concordance of HSI was greater than stroboscopy. The diagnosis of presbyphonia requires visualization of exaggerated mucosal wave excursions seen with vocal fold atrophy, which may be sub optimally, visualized using stroboscopy.
- Interestingly, the diagnostic identification of sulcus vocalis, which classically presents diagnosis challenges, was not readily enhanced by HSI. This finding could be due to the absence of abductory views and the limitations of medial edge visualization provided during HSI.

Overall, as individual laryngeal examination techniques, stroboscopy and HSI provided exactly the same likelihood of predicting the treatment diagnosis. Nevertheless, HSI was not identified as a significantly more efficacious modality. This is in agreement with previous comparative studies that noted HSI to function only in a complementary manner to stroboscopy. Based on the results of the study, HSI appears to be without improved diagnostic capacity as a stand-alone technique apart from stroboscopy. The authors conclude that overall, HSI did not improve the diagnostic accuracy above stroboscopy alone.

CHAPTER III

METHOD

Participants

The participants in the present study were grouped under two categories, the experimental group and the control group. Five hundred individuals presenting with varied voice complaints to the Department of Clinical Services, AIISH, in the age range of 10 to 80 years were recruited as the participants for the experimental group. In order to comprehend the varied Electroglottographic and stroboscopic characteristics in phononormic individuals, 101 vocally healthy individuals in the age range of 20 to 60 years were recruited to constitute the control group. Selection of these phononormic individuals was based upon a checklist devised by the researchers. The checklist is presented in Appendix1 (* only those participants who passed a minimum of 4/8 questions in the checklist were recruited as the subjects). As the voice disordered clients visiting AIISH ranged from as young as 10 years of age to as old as 80 years an extensive age range had to be considered. For the ease of comparison of results between these subjects, the age range was subdivided into five groups, 10-18, 18-30, 30-50, 50-65 and 65-80 years. This subdivision of age groups was further based on factors such as physiological changes (pubertal changes that take place within early years of age and neurological and cartilaginous changes at geriatric ages), occupational requirements of voice (that are peak in the ages of 20-60 years). Two main exclusion criteria were set for the selection of participants in the experimental group. These were

- Significant histories or confirmed presence of debilitating communicable diseases and evident carcinomatous lesions (involving the oral cavity and throat structures) at the time of testing

- Presence of extreme fat tissue around the neck and the presence of extremely large head-neck circumference.
- (* the age range for phononormic individuals was set as 20-60 years owing to the fact that with increasing age, natural physiological changes in the vocal folds lead to alterations in the quality of voice and its phononormic property is lost).

Procedural protocol

The procedural protocol pursued in the present study was sub divided into various phases. In the **first phase**, a detailed case history (concerning their presenting complaints, duration, severity, presence of vocal abuse/misuse, history or presence of other physical ailments) from all the individuals presenting chiefly with voice complaints visiting the Department of Clinical services, All India Institute of Speech and Hearing, Mysore was procured. Following the case history, based upon the exclusion criteria set, participants were then chosen for the study. While obtaining the history, it was observed if any phonotraumatic behaviours such as throat clearing, hard glottal attack, tension in the laryngeal muscles; abnormal breathing patterns etc were present. The participants were then counselled regarding their present vocal condition and the need to undergo following voice evaluations. Following this, consent from them regarding their active participation in the study was also obtained.

In phase 2, after procuring case history details, the participants were made to individually undergo the electroglottographic (EGG) procedure. In this procedure, the participants were first comfortably seated with their neck straight up. Following this, two gold plated electrodes of the CSL (Computerized Speech Lab) system were placed on the adjacent sides of the participant's thyroid lamina and were then secured in place with a Velcro collar at the position. An Electroglottograph (KayPentax model 6103) was employed to obtain information regarding the vocal folds contact patterns that constitutes a vital aspect of vocal function. Ethical clearance and informed consent were obtained from all the participants by the principal investigator and the research officer. Figure1 provided below illustrates the placement of electrodes and the hardware component of the EGG tool utilized.

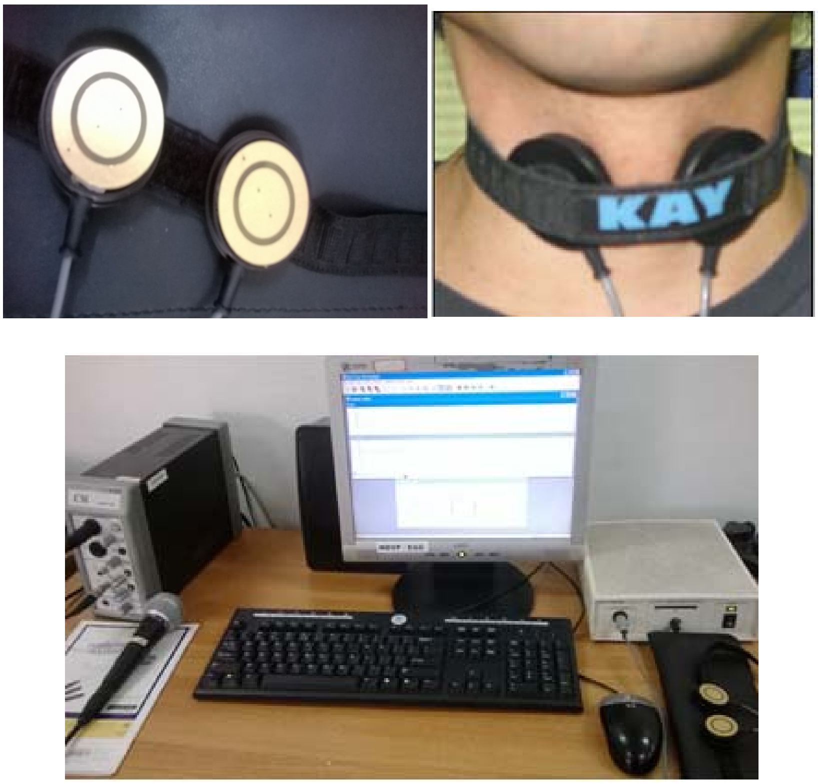


Figure 3.1, Placement of electrodes and the EGG hardware.

A sustained vowel task was employed for obtaining the data in which each participant was instructed to produce their typical voice by chanting ‘‘1, 2, 3./i/’’ and sustaining the phonation of the vowel for a minimum of 5-7 seconds. This method tends to elicit a vocal F0 similar to the habitual speaking pitch and loudness and hence this was incorporated in the present study also. The phonation was thus recorded. The working principle of EGG is as follows: Passing a high frequency (5-10 Mega Hz) low voltage current (< 2 mA) through the electrodes captures the vocal fold contact pattern reflecting it as a waveform on the monitor. High conductance and high impedance of the electric signal were thought to be analogous to vocal folds contact or adduction and vocal folds separation or abduction respectively. Four main features of this waveform observed and their equivalent counterparts were: (I) a steep rising edge corresponding to the closing phase (II) a maximum peak, corresponding to maximum closure (III) a shallow falling edge analogous to opening phase and (IV) a trough essentially constant with time analogous to the open phase or the abductor phase of vocal fold vibration (Lecluse, 1977). The relative lengths of these phases were found to change with voice quality. Thus the EGG waveform represented the phases of vocal-fold vibration and its relative amplitude was related to the vocal-fold contact area. Interpretation of the waveform was carried out by mainly by analyzing its wave morphology. Various EGG waveforms were obtained and based upon the wave morphologies; similar patterns were grouped, classified and numerically coded. On the basis of available literature in this purview and on the clinical experience of the researcher, certain wave morphologies were theorized to signal certain pathological/normal voice conditions, which are mentioned below (along with the numerical codes that were provided for each). Normal waveform (Figure 3.2) (implying a normal vocal mechanism structure and functioning, devoid of any supra glottal compressions too): **1** (* Waveform with uniform symmetry of peaks being nearly sinusoidal)

I. Presence of notch like or double peaks in closing and closed phase (indicating mass lesions and or Sulcus types)

- Right sided double peak: **2**

  (*Notch/peak like emergence towards the right side of the highest peak)

- Intermittent double peak: **3**

  (Notches/peaks present intermittently in a few cycles)

- Left sided double peak: **4**

  (*Notch/peak like emergence towards the left side of the highest peak)

II. Fuzzy or irregular waveform (implying laryngeal inflammations, infections and certain neurologic palsies and/ neurologic tremors)

- Irregularity in periodicity: **5**

  (*Changes in the spatio-temporal patterns of EGG waveforms over time- Shaw & Delyski, 2007)

- Irregularity in cycle to cycle morphology reduplicability: **6**

  (* Impaired replicablity of waveform morphology in successive cycles)

III. Tremulous waveform: **7**

(* Presence of symmetric fluctuations in all the phases and cycles of the EGG waveforms)

IV. Prolonged phases (indicating inadequate glottal closure/ glottic chink and conditions associated with it)

- Prolonged open phase: **8**

  (Prolongation of the **open phase** alone in comparison to other phases of the cycle)

- Prolonged closed phase: **9**

  (*Prolongation of the **closed phase** alone in comparison to other phases of the cycle)

- Prolonged closing phase: **10**

  (*Prolongation of the **closing phase** alone in comparison to other phases of the cycle)

- Prolonged opening phase: **11**

  (*Prolongation of the **opening phase** alone in comparison to other phases of the cycle)

V. Others (*which might be indicative of diplophonic phenomenon, certain types of MTD, etc):

  - Bitonal waves: **12**

(*Presence of abnormal individual waves in between the regular cycles of EGG waveform- Dejonckere & Lebaq, 1983)

- Reduced amplitude waves: **13**

  (*Diminished waveform pattern- Lim et al, 2009) (* These patterns could not be ascertained to signal specific pathologic conditions based upon the existing literature as well as the researchers experience and hence, these were grouped under “others”)

Following this, in **Phase 3** the participants were made to undergo the Videostroboscopic procedure. The *Digital Video Archive Software (DiVAS)* version 2.5 from *Xion Medical* was used to video record. The stroboscope effect from the hardware, *Xion Endo Strobe-D* and the LED light source from the hardware, *Xion Xenon R-180* were utilized. During this procedure, the rigid scope with a camera attached from the hardware of the system was inserted into the back of the subject's oropharynx by an experienced otolaryngologist. An audio-video recording was procured of laryngeal movements during the production of the sustained vowel /i/ at comfortable pitch. A Panasonic recorder and colour monitor were used to record and later observe vocal fold function. Figure 3.15 illustrates the stroboscopic procedure that was carried out as a part of the customized data collection procedure.

Figure 3.15, Illustration of the stroboscopic procedure that was carried out as a part of the customized data collection procedure

Subjects who were overly sensitive to the presence of the scope in the oral cavity or who had a hyper active gag reflex were given a topical anaesthetic (xylocaine) to diminish it. The stroboscopic recordings were then completed following the observation of the glottic structure and functioning (of vocal folds) and the supraglottic structures (epiglottis, ventricular folds, arytenoids, aryepiglottic folds) and their functions. Following this, the otolaryngologist accompanied by an experienced SLP and the Research officer commented upon the various aspects of glottic (glottic closure, phase closure, phase symmetry, mucosal wave, periodicity and amplitude of vibration) and supraglottic structures (Epiglottis, Ventricular folds, Arytenoids) based upon a stroboscopic report form developed by the Voice Clinic, AIISH Mysore (the stroboscopic report form utilized in the study is presented in Appendix II). Finally after reviewing the comments on the various features of glottic and supraglottic structures, and the case history details, a diagnostic conclusion was inferred upon.

In **Phase 4,** all the 517 participants data were classified based on the finer similarity in the stroboscopic diagnosis and case history details under: normal vocal folds structure and functioning, mass lesions (vocal nodule, polyp, granulomas and carcinomas), vocal fold paralysis/ paresis (unilateral/ bilateral), glottic chink/ inadequate glottic closure (anterior, posterior, hour glass, irregular and spindle shaped), laryngeal infections (laryngitis), muscle tension dysphonia, spasmodic dysphonia, puberphonia, sulcus vocalis and essential voice tremors. These diagnostic conclusions too were grouped and numerically coded for the purpose of obtaining the extent of association with the diagnostic inferences from the EGG patterns. Categorizing of the waveforms, inferring and coding of the stroboscopic diagnosis was conducted by the researcher in the presence of other SLP's and the otolaryngologist posted in the department and hence, reliability of the measures was established then and there itself. Coding followed is as mentioned below

- Normal vocal folds structure and functioning: **1**
- Early vocal nodules/ early nodular changes of the vocal cord mucosa: **2**, fully developed vocal nodules: **3,** vocal polyps: **4**, cysts, early carcinomatous and edematous lesions: **5**
- Neurological conditions: Vocal fold paralysis: **6**, vocal fold paresis: **7**, voice tremors: **8,** hemangiomas: **9**
- Vocal fold infections and inflammations: **10**
- Glottic chink: anterior glottic chink: **11**, posterior glottic chink: **12**, spindle shaped glottic chink: **13**

- Others: Sulcus Vocalis: **14**, muscle tension dysphonia: **15**, spasmodic dysphonia: **16**, Puberphonia: **17**, plica ventricularis: **18**, glottic web: **19**

Phase 5 constituted of examining and compiling the normative data. In this phase of study, a checklist prepared to recruit perceptually phononormic individuals was employed. This checklist was administered on individuals in the age range of 20-60 years and only those individuals who passed the checklist were selected as subjects for the study. It was ensured that a minimum of 101 subjects who passed the checklist were chosen as normative subjects. After selection of participants, all of them were made to undergo the stroboscopic procedure by the otolaryngologist. All the parameters mentioned in the stroboscopic form were rated and a confirmed phonatory inference was derived. On examination it was observed that a few of the participants exhibited some form of posterior falling epiglottis and posterior glottic chink features that were asymptomatic to them. Since “perceptually phononormic” feature was the main criteria and as many subjects demonstrated these slight deviations, they were treated as normal variations itself and were considered under the control group. Hence on all these participants, EGG was also carried out. Following this, the EGG waveforms were analyzed qualitatively, and the resulting morphologies was grouped and coded on similar lines as done for the experimental group.

Using the Pearsons chi square test for independence of attributes, the extent of correlation of the diagnostic labels inferred from EGG with that of the stroboscopy was tracked upon for the experimental group. Further, the percent mean frequency of EGG pattern hierarchy for each of the stroboscopic diagnostic labels too was calculated. In addition to correlation, mean frequency of the EGG wave patterns under each of the stroboscopic diagnosis was also carried out mainly to decipher the type and hierarchy of varied EGG patterns that can be associated with those conditions. As the age groups was subdivided into

10-18, 18-30, 30-50, 50-65 and 65-80 years, the extent of EGG correlation with the stroboscopic results was noted across these age ranges also. This was intended to know if the extent of correlation between the two instrumental techniques varied significantly as a factor of advancing age. The extent of association between the stroboscopic findings and the EGG wave morphology patterns was carried out for the 101 participants of the control group also.

CHAPTER IV

RESULTS AND DISCUSSION

The present study was conducted with the following objectives

- To estimate a qualitative relationship between electroglottogram (EGG) patterns and videostroboscopic findings in disordered as well as phononormic individuals.

- To estimate the sensitivity and specificity of electroglottographic and stroboscopic findings in recognizing anatomical and physiological vocal fold change.

The study involved 517 individuals with dysphonia visiting All India Institute of Speech and Hearing (AIISH) who were recruited under the experimental group. EGG followed by videostroboscopy was carried out and the findings were documented. 101 phononormic individuals (without any voice complaints) were selected under the control group based upon a checklist devised (Appendix 1). These participants were made to undergo videostroboscopic procedure first followed by EGG and the results of both were documented. In order to accomplish the first objective of the study, i.e., to estimate a qualitative and quantitative relationship between EGG patterns and stroboscopic findings, correlational/association analysis was undertaken.

4.1. Correlation of EGG with videostroboscopy in the experimental group

EGG followed by videostroboscopy was carried out for all the participants (517) under the experimental group. During the EGG procedure, all waveforms obtained were numerically coded based upon the gross similarity of the wave morphology and were diagnosed to signal certain vocal pathologies. Following this videostroboscopy was performed on all the participants and diagnostic conclusions were drawn. Similar diagnostic labels were grouped and coded.

The statistical tools, Chi-square test of association and Cramers-V tests were conducted to assess the association/correlation between EGG and stroboscopic results and the extent of association. On applying the Chi-square test of association, a statistically significant association ($p = 0.001$) was found to exist between the overall EGG wave patterns and the findings on videostroboscopy. On applying the Cramers-V test to measure the extent of association, a moderate association level ($p = 0.542$) was found to exist between the overall results of EGG and stroboscopy.

There are reports in literature that advocate and emphasize EGG to be carried with synchronized stroboscopy as both the techniques are in good agreement and overcome the inherent limitations of each other (Pedersen, 1977; Anastaplo & Karnell, 1988; Hill, Meyers & Scherer, 1990; Gould, 1984). Nevertheless, there is a dearth of studies in literature on correlations between data of EGG and/ videostroboscopy with the results of laryngeal phonatory function assessments using other measurements (Uloza, Vegiene & Saferis, 2013).

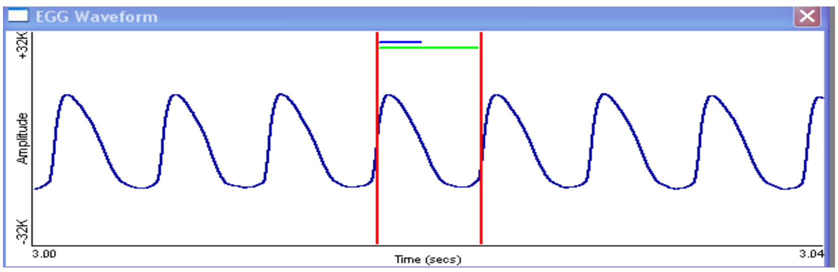
Statistically good association between the results of EGG and stroboscopy obtained in the present study can be further supported by certain factors and other reports in literature. One of the major reasons for a good association between the results of both could be owing to analogous information both the techniques provide. EGG provides information majorly about the contact patterns of vocal folds, thereby reflecting the vocal cord vibratory properties. Similarly, stroboscopy provides an equivalent, much detailed information about the vibratory patterns itself through a better and direct visualization system.

Literature in this purview evidences studies reporting overlap or correlation of EGG data with other methods of glottal function including videostroboscopy, Photo glottography (PGG), High speed Imaging (HSI) etc. Fairly good correlation between EGG and stroboscopy obtained in the present study can be supported by the findings of Pedersen etal. (1973) who reported a good harmony between the results of stroboscopy and EGG. Further, Baer et al. (1983) reported that the correspondence of EGG signal with other measures of glottal activity confirms it to be a valid indicator of vocal fold contact. On the same lines, Hill, Meyers, and Scherer (1988) compared the success of four clinical techniques for voice analysis (videolaryngoscopy, videolaryngostroboscopy (VLS), electroglottography (EGG), and acoustic perturbation analysis). Here the authors reported that VLS, EGG and acoustic recordings are useful and complementary clinical tools in the evaluation of laryngeal function. A moderate correspondence between VLS and EGG analysis for the estimation of glottal adduction was reported, there by perfectly supporting the findings of the present study. Likewise, Trapp et al. (1988) and Hertegird et al. (1995) reported that EGG waveforms are strongly related to the measures of glottal insufficiency as observed through stroboscopy.

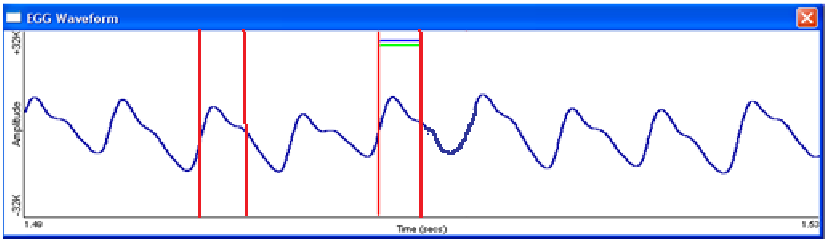
4.2. EGG waveforms in various laryngeal pathologies

On analyzing the EGG waveforms of 517 cases, they could be classified into 13 types of wave morphologies based on the similarity of patterns obtained. These are

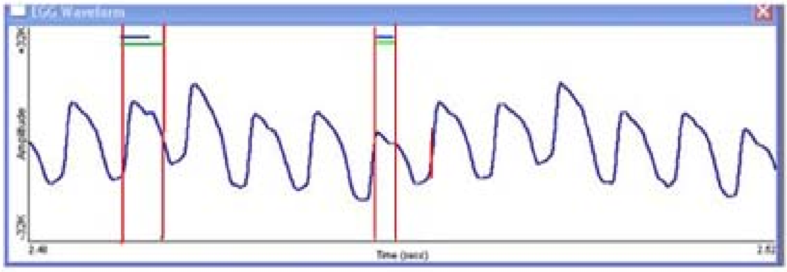
1. Normal waveform

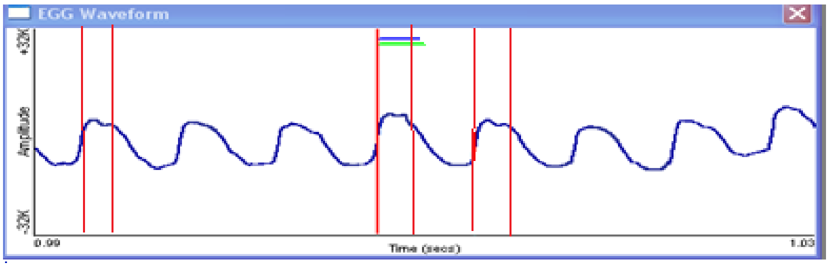


2. Waveform with right sided double peak/notch

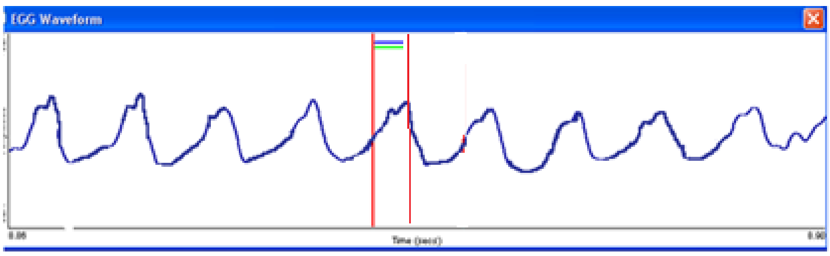


3. Waveform with intermittent double peak

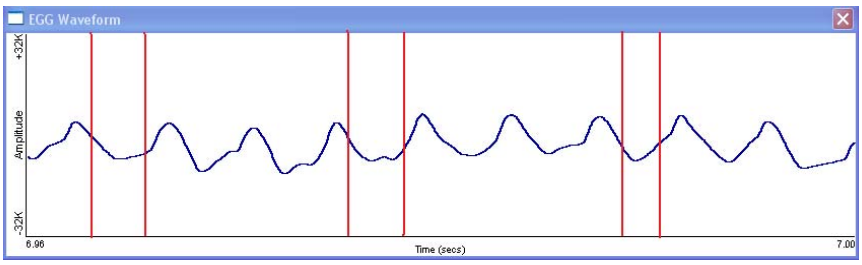




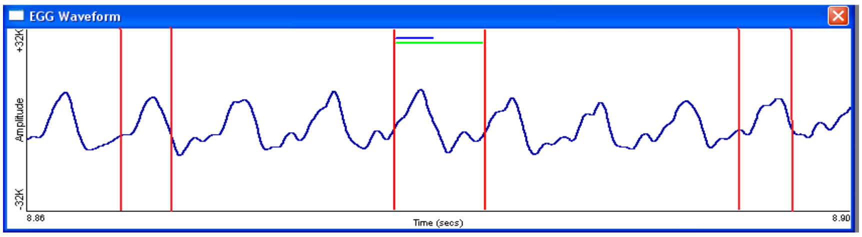
4. Waveform with left sided double peak/notch



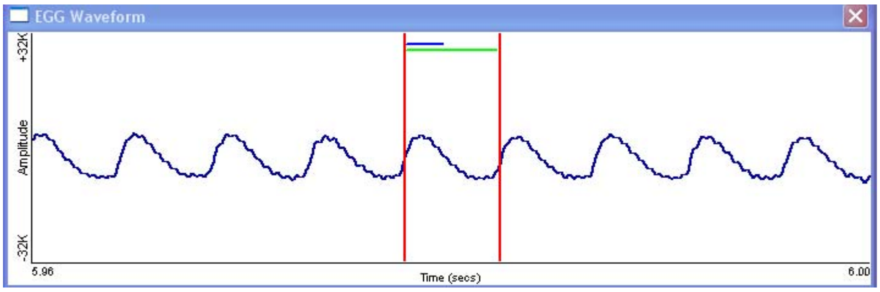
5. Waveform with irregularity in periodicity



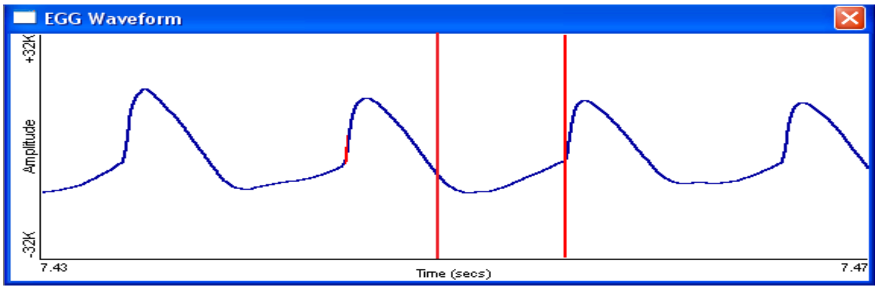
6. Irregular waveform with altered cycle-cycle replicablity



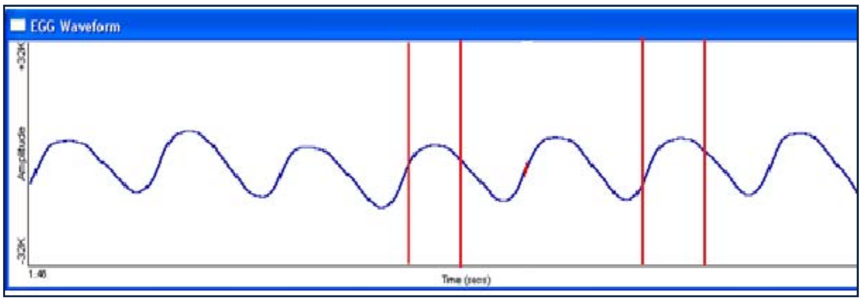
7. Waveform with tremulous pattern



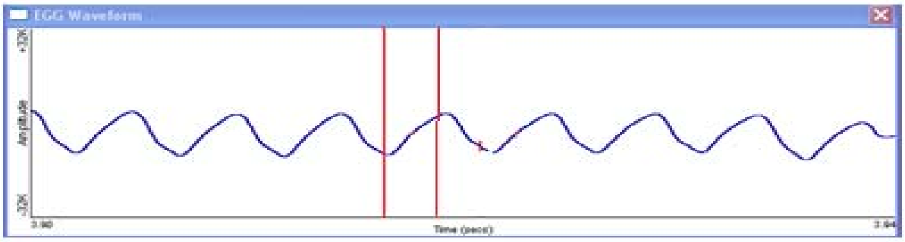
8. Waveform with prolonged open phase



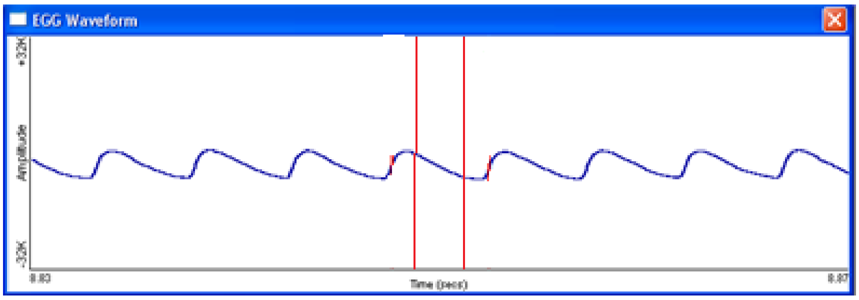
9. Waveform with prolonged closed phase



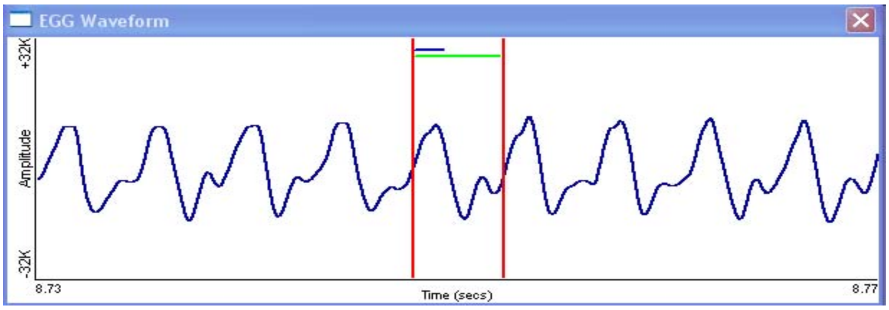
10. Waveform with prolonged closing phase



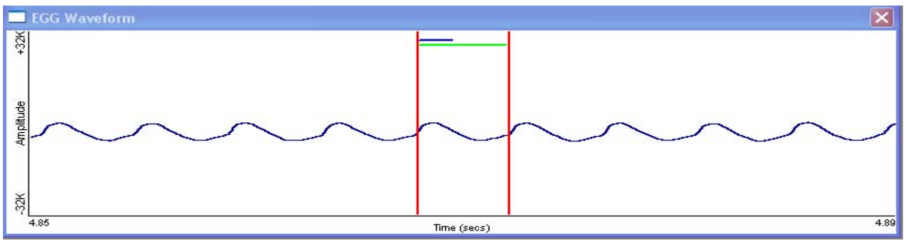
11. Waveform with prolonged opening phase



12. Waveform with biphasic peaks



13. Waveform with reduced amplitude of peaks.



When these 517 participants were subjected to stroboscopic examination, the following conditions were observed.

1. Normal vocal cord structure and functioning

2. Early developing nodules/ early nodular changes
3. Developed nodules
4. Polyps
5. Initial stages of carcinomatous lesions/ cysts/ other edematous mass lesions
6. Vocal fold paralysis
7. Vocal fold paresis
8. Tremulous vibrations (essential voice tremor/neurological tremors)
9. Hemangiomas
10. Inflammations/infections
11. Glottic chink (anterior/posterior/spindle shaped)
12. Sulcus vocalis
13. Muscle tension dysphonia
14. Spasmodic dysphonia
15. Puberphonia
16. Plica ventricularis
17. Laryngeal web.

The following section presents each of the EGG wave morphologies and the hierarchy of laryngeal conditions they represented.

4.3.1. Various laryngeal conditions associated with ***normal EGG waveform***

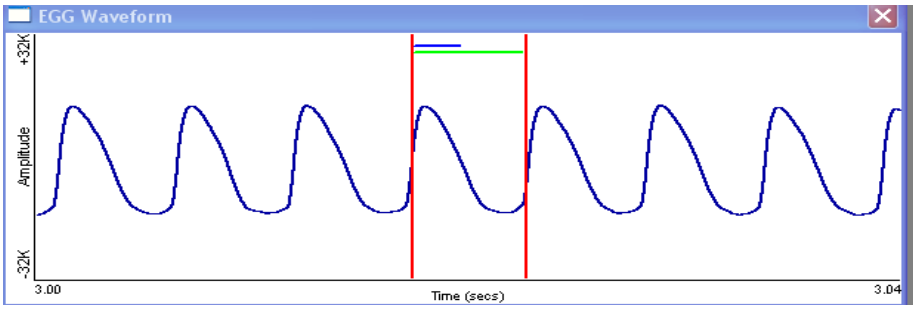


Figure 4.1, Morphological representation of a normal EGG waveform

A total of 127 participants of the overall 517 voice cases, were found to possess normal EGG waveforms (Fig, 4.1), though they presented with certain voice complaints. On stroboscopic examination, few of these participants (with normal EGG waveforms) were found to exhibit some laryngeal pathological conditions. It can be inferred that the presence of just a normal waveform need not entirely signal normal vocal mechanism and could be present in slightly altered laryngeal conditions also. This indicates that persons with mild laryngeal abnormalities may also show a normal EGG wave pattern. Figure 4.2, demonstrates the hierarchy of various laryngeal conditions that had normal wave morphologies.

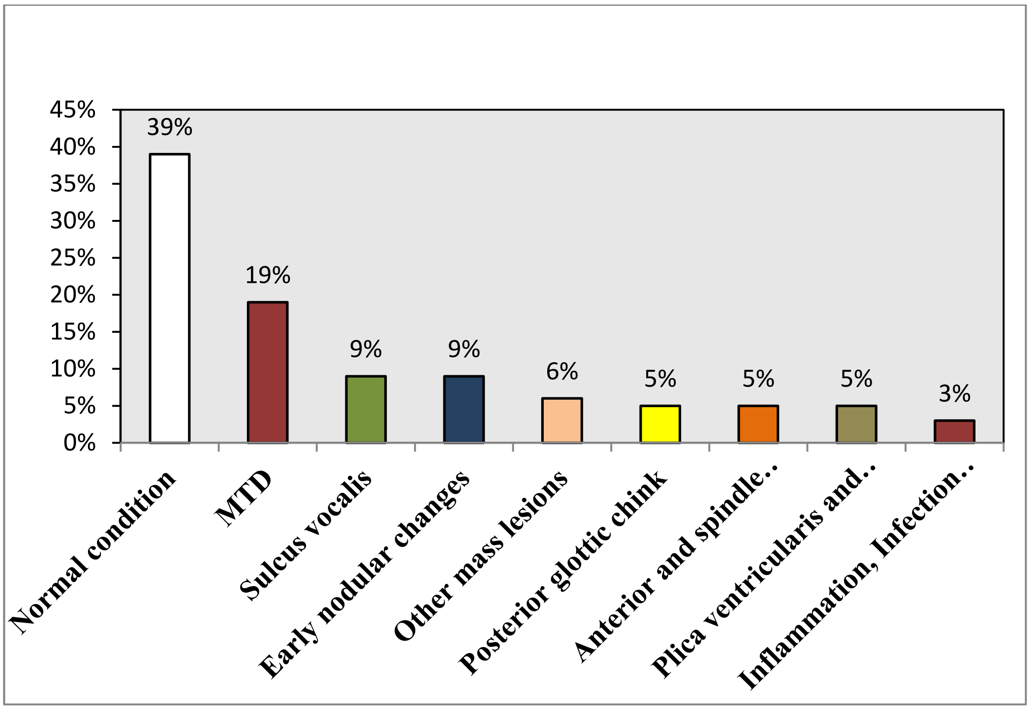


Fig 4.2: Various laryngeal conditions associated with normal EGG waveform

A total of 39% (50/127) of subjects with normal wave morphology demonstrated normal structure and functioning of the vocal mechanism on stroboscopic examination. This is possible as these individuals presented with complaints of throat pain, throat irritation and early vocal fatigue majorly than quality related voice changes.

19% (25/127) of the subjects with normal waveforms were found to have some type of muscle tension dysphonic features on stroboscopic examination. In the present study, subjects who had normal EGG waveforms but with MTD like features under stroboscopy, were found to be under the primary MTD type. Probable reasons for this are

- In the current study, stroboscopy could not be carried out immediately after EGG examination. In a few of the patients (13/25), vocal loading instances were reported just prior to the stroboscopic examination. Since MTD is a transient condition, vocal loading could have led to the emergence of MTD features which were otherwise obscured during the EGG procedure. This observation is in consonance with the findings of Jilek, Marienhagen and Hacki, 2004 who reported that voices show hyperfunctional behaviour immediately after vocal loading tasks
- In the present study, most of the participants (18/25) diagnosed as MTD having normal EGG waveforms exhibited mild MTD II and III features with posterior glottic chink. Normal waveforms in them could be due to the mild type II and III features being anterior posterior / latero medial compressions, not directly hampering the contact of vocal folds.
- In few participants (6/25), diagnosis of MTD itself could be questionable. MTD features could have emerged owing to the tension and posture associated with the procedure during stroboscopic evaluation mimicking MTD features (tension and compressions). Case histories of these patients revealed no significant MTD symptoms ie, no history of strain/tension during speech tasks, vocal fatigue or excessive vocal loading instances. Evident voice complaints of these patients were: presence of breathy quality of voice, feeble voice, throat irritation etc. In these cases, a normal waveform could be present with MTD like features evidenced only during the stroboscopic examination.

Normal waveforms were found in 9% (12/127) of participants with sulcus vocalis. In the present study, all the sulcus cases with normal EGG waveforms were found to possess the physiologic type sulcus. In these participants, the physiologic sulcus manifested as a minor linear groove/depression extending posterior to the vocal process of vocal folds with minimal alterations of the mucosal wave. As the mucosal wave was spared and the superficial lamina propria and vocal ligament was intact, the contact pattern of vocal folds was almost normal.

As evident from Figure 4.2; 9% (12/127) of participants with normal EGG waveforms were found to have early developing nodules on stroboscopic examination. Early nodular changes occur prior to the complete development of vocal nodules. These early nodular changes are characterized by local vascular congestion with edema due to repeated collision near the anterior mid junction of the vocal folds (Altman, 2007). These changes though evident on stroboscopy, do not hamper the contact of the vocal folds until hyalinization of Reinke space, thickening of overlying epithelium and development of epithelial hyperplasia. This might result in almost normal contact patterns reflected as normal EGG waveforms. Augmenting this, in a study by Motta etal (1990), 28% of nodule patients were reported to demonstrate the presence of normal wave morphologies.

5% (6/127) of participants with normal EGG waveforms were found to have posterior and anterior/spindle shaped glottic chink each on stroboscopic examination (Fig 4.2). In general, glottal closure during phonation is more complete in men than in women. Slight glottal gaps have been reported in vocally normal young women, with posterior chink reported to be particularly prevalent in young women (Sodersten & Lindestad, 1990). In the present study also, all the participants with slight posterior glottic chink who had normal EGG waveforms were females within 15-30 years of age. The presence of normal EGG waveforms in these participants could be further explained by the following points:

Specifically, the distance between the bilateral crico-arytenoid joints relative to the ventro-dorsal dimension of the glottis is greater in females than in males. In addition, posterior glottic chink in young women is reported majorly in the cartilaginous glottis not impacting much on the vibratory qualities of vocal cords. Perceptual evaluation revealed mild hoarse (in two participants) and mild breathy voices (in four participants).

Presence of spindle shaped (2/6) and anterior glottic chink (3/6) was evident in overall 5% (6/127) of participants who had normal EGG waveforms. In three participants who had anterior glottic chink, there was an almost intact mucosal wave with a slight chink near the anterior commissure of the vocal cords. This might have reflected as normal contact patterns on the EGG waveform. Spindle shaped glottic chink being reflected as normal EGG patterns could be attributed to certain extrinsic variables during the EGG procedure.

As can be inferred from Figure 4.2; normal EGG waveforms were also found in participants with polyps and other mass lesions (6%), acute laryngitis and vocal fold paralysis (3%), puberphonia and plica ventricularis (5%). Normal waveforms were seen in four participants with vocal cord polyps, two of which were pedunculated in nature, not interfering with the normal vibratory patterns. In 2 other participants, the polyps were relatively small in size and normal EGG waveforms were present. This finding can be attributed to the fact that small polyps generally have intact mucosal waves and hence do not alter normal vibratory characteristics (Altman, 2007). This observation can be further augmented by the reports of Motta et al. (1990) who found normal EGG waveform patterns in a minor percentage of polyp cases.

Two participants with normal EGG waveforms were found to have initial carcinomatous lesions. In both these participants, there were irregular vocal fold surfaces, but the mucosal wave and vibratory patterns were near normal leading to the appearance of normal waveform patterns on EGG.

Presence of normal EGG waveform was found in 3% of participants with acute laryngitis (2/127) and vocal fold paralysis (1/127). In case of acute laryngitis, this finding could be due to the incidence of inflammatory changes still in developing stage not altering the normal vibratory properties. Case histories of both these participants revealed chief complaints of throat irritation and pain during swallowing rather than major change in the quality of voice. In one subject with right vocal cord paralysis, normal EGG waveform was obtained. In this case, mucosal wave was inconsistently present and phase symmetry was preserved. History revealed no major symptoms of stroke/paralysis including physical weakness, loss of sensation etc, nor incidence of any surgery that would trigger paralysis (like thyroidectomy etc).

5% of participants with puberphonia (4/127) and plica ventricularis (3/127) had normal EGG waveforms. In cases of puberphonia, the laryngeal structures develop and progress to prominent pitch changes but the vibratory/contact patterns may be preserved. Case histories of these four participants revealed major complaints of high pitch rather than quality related changes resulting in normal EGG waveforms. In case of plica ventricularis, it is the movement of the ventricular folds in addition to normal vocal cord vibrations. This ideally will result in double pitch perceptions. In these cases normal EGG waveforms can be attributed to the hypertrophied movements of ventricular folds alone, not hindering the normal movements of true vocal cords.

4.3.2. Various laryngeal conditions associated with *right sided notch/double peak* on the EGG waveform

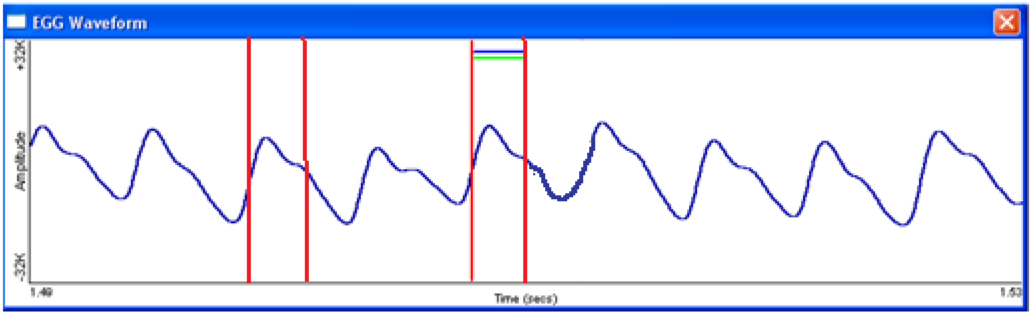


Figure 4.3, Morphological representation of EGG waveform with right sided double peak

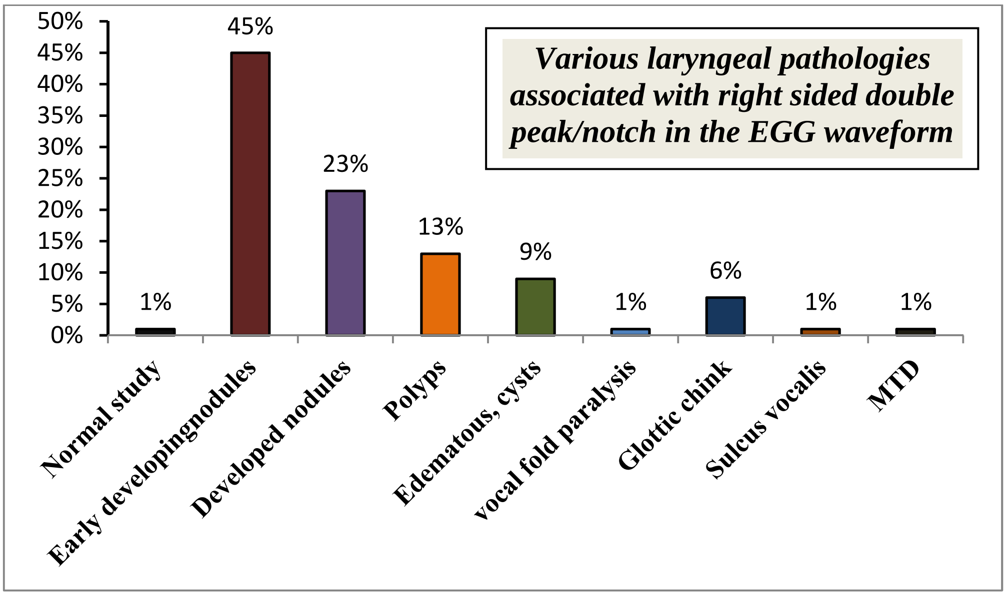


Figure 4.4, Various laryngeal pathologies associated with right sided double peaked/notched EGG waveform

A total of 91 participants of the overall 517 cases, were found to have right sided double peak/notch in the closed phase (Figure, 4.3) of the EGG waveforms. On stroboscopic examination, these individuals exhibited some form of mass lesions as well as a few other laryngeal pathologies, the hierarchy of which is presented in Figure 4.4.

4.3.2. A. Mass lesions associated with right sided peak/notch in the EGG waveform

As evident from Figure 4.4, in the present study right sided notch/double peaks in the EGG waveforms were present in 45% (41/91) of the participants with early nodular changes and 23% (21/91) of the participants with developed nodules. In cases of nodules, stroboscopy reveals, slightly decreased amplitude of mucosal wave that is generally symmetric and an hourglass-shaped glottal closure (Altman, 2007). Since there is decreased phase closure and the mass interfering with normal vibrations, a notch like is most probable to occur in the adductory phase of the EGG waveform.

The present finding is at par with certain other studies of EGG waveforms in case of nodules. Van Michael (1967) and Motta et al. (1990) reported the presence of a “notch” (double peaked appearance) in the portion responding to the adductory phase of the vibratory cycle.

13% (12/91) of participants with right sided double peak evidenced vocal polyps on stroboscopic examination. This finding is in consonance with certain studies that report presence of notch patterns in EGG waveforms in case of polyps. Motta et al. (1990) reported that, single and double notches were observed in 25% and 68% of patients with vocal polyps. In another study by Sreedevi et al (1993), EGG waveform pattern with a double peak in the adductory phase, was reported to be suggestive of mass on vocal folds in general. The physiological mechanism behind such an inference is attributed to the glottal mass lesions which additionally, are assumed to achieve contact during adductory phases of vibration resulting in double peaked notch like patterns in the EGG waveform.

9% of patients with right sided double peak were found to have edematous lesions, cysts and other mass lesions. This is in consonance with the study by Motta etal (1990) who reported the presence of single notch (24%) and double notch (72%) in the glottographic waveforms of individuals with rinkes edema. It could be further speculated that, since these mass lesions are outward protrusions on the vibrating surface of vocal folds; these interfere during the vibratory phases resulting in notch/peak like patterns in EGG waveforms.

Case histories of these participants with right sided double peak/notch also revealed certain strong predisposition to be having nodules as the underlying pathological condition. A large number of patients (63/91) having right sided double peak on the EGG waveform and having early nodular changes/developed nodules/polyps/cysts were professional voice users. Teachers were the most prevalent (53/63) professional voice users among them. High incidence of mass lesions in teachers can be augmented by a number of other reports and findings. Sarfati (1989) evaluated 90 French teachers referred for vocal disorders, and pathology was found in two thirds overall, with pseudo cysts or nodules in one third overall. Fritzell (1996), reports that teaching constitutes one of the 10 occupations which frequently requires medical attention for voice difficulties. In a Finnish study, Smolander and Huttunen (2006) surveyed 181 teachers, of whom 42% reported frequent voice symptoms, and 10% had history of vocal nodules. Altman (2007) reports that teachers are perhaps the largest group of voice professionals who seem to be at higher risk for the development of hoarseness and vocal masses.

Incidence of these right sided notch/peaked waveforms who had some form of mass lesions was also present in a large number of females (56/91) and children (20/91). The prevalence of voice problems were reported to be more in females than males (Roy et al, 2004). Altman (2007) reported that mainly, nodules are seen in children, adolescents, and predominantly female adults working in professions with high voice demands. High incidence of mass lesions in females can be attributed to the effect of higher vibratory rate on vocal folds in case of females (Svec, 2007). Additionally, the softer intensity of female voices leads to more hyperfunction in adult professional environments with louder background noise (Altman, 2007).

4.3.2. B. Other laryngeal conditions with right sided double peaked EGG waveforms

As evident from Fig 4.2, there were certain other conditions in which right sided double peak in the EGG waveform was present, but in relatively low percentages. These conditions were: Glottic chink (6%), normal vocal cord structure and functioning (1%), vocal cord paralysis (1%), sulcus vocalis (1%) and MTD (1%).

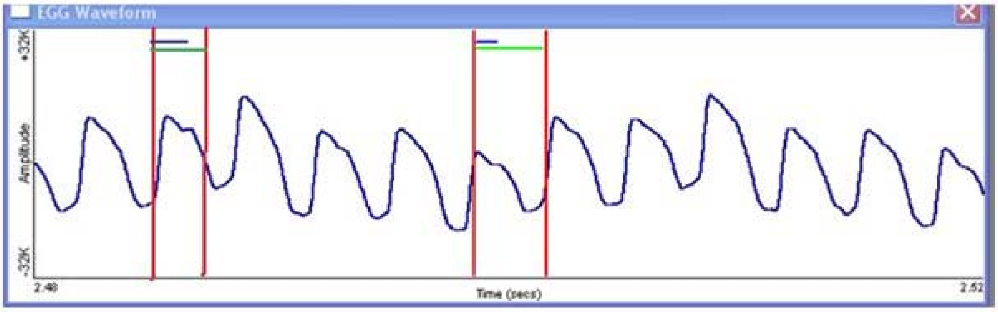
In two participants' with glottic chink, on stroboscopic examination, an hour glass pattern was evident with very minute early nodular changes on the anterior-mid third of vocal cords, but a confirmative diagnosis of nodules could not be made. In these cases, possible reason for the right sided double peak could be attributed to the EGG's sensitivity specifically in detecting early precipitating nodular changes on surface of vocal cords.

Incidence of sulcus vocalis in one participant with right sided double peak in the EGG waveform was evidenced. Case history of this participant revealed the occurrence of vocal cord cyst three years ago prior to the day of examination. It has been reported in literature that vocal fold cysts are closely related to the development of sulcus deformity (Lim, Kim & Choi, 2009). In this participant, due to the past history of cyst that perpetuated the development of sulcus groove, spotted mass on the surface epithelium along with the sulcus groove might have caused the double peaked EGG waveform.

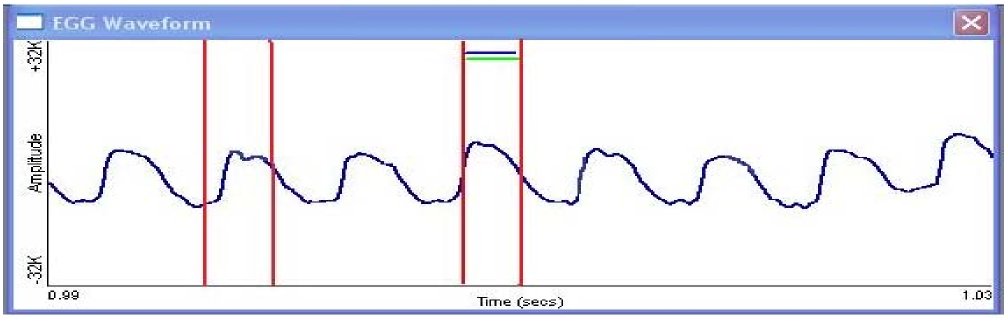
One participant with right sided double peak on EGG waveform was found to exhibit MTD like features on stroboscopic examination. Case history details of this participant revealed the presence of early vocal nodules seven months prior to the stroboscopic examination. Hence, the development of secondary MTD like features associated with organic vocal pathologies could have led to such a waveform with MTD features.

Right sided double peak in the EGG waveform was also noticed in other participants of glottic chink, vocal cord paralysis and normal conditions but in very limited numbers. This could be owing to lacunae in the sensitivity of EGG in detecting specific vocal pathologies.

4.3.3. *Intermittent double peak/notch* in the EGG waveform and the associated laryngeal conditions



(a)



(b)

Figure 4.5 (a,b), Morphological representations of two EGG waveforms showing intermittent double peaks

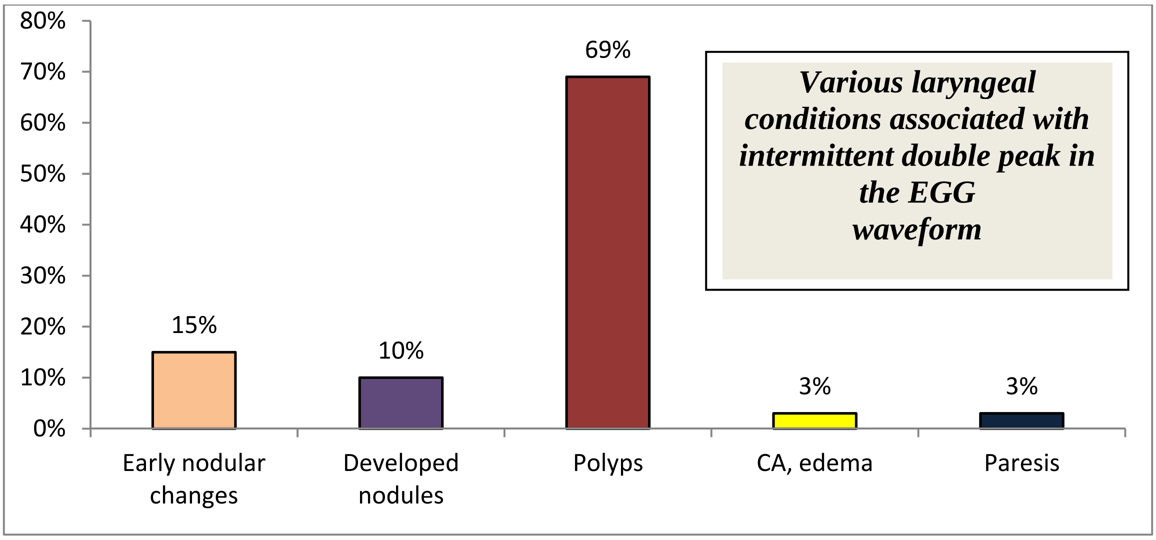


Figure 4.6, Various laryngeal conditions associated with intermittent double peak in the EGG waveform

Intermittent double peak/notch like pattern in the EGG waveform was characterized by double peaks occurring inconsistently in certain adductory phases of the waveform (Figure 4.5). Figure 4.6 depicts the various laryngeal pathologies that were associated with intermittent double peak in the EGG waveform. 69% (22/32) of participants with this type of EGG waveform were found to have pedunculated/sessile polyps on stroboscopic examination. As pedunculated polyps have stalks attached at the base, they interfere with the vibratory patterns at times and erratically interrupt the normal vibratory patterns. This nature of pedunculated polyps might have reflected on the EGG waveform as intermittent double peaks in the adductory phases. In addition, polyps are reported as asymmetric masses on vocal folds that have more vasculature and result in chaotic vibrations and aperiodic mucosal waves (Altman, 2007). These chaotic vibrations could also be thought to cause intermittent or irregular double peaks in the EGG waveforms.

As evident (Figure 4.6), 17%, 10% and 3% of participants with early nodular changes, developed nodules and cysts were found to have intermittent double peaks on the EGG waveform. Since these mass lesions too have a protruding effect from the surface of the vocal folds, and result in disorganized/fuzzy vibrations, intermittent double peaks could have been possible. One participant was found to have left vocal cord cyst on stroboscopic examination. There was much diminished mucosal wave on the side of the cyst and phase closure was significantly open. Inconsistent double peak in this case could be possibly due to the presence of asymmetric mucosal wave between the two cords and the sub epithelial mass lesion interfering intermittently with normal vibration.

In one participant who had intermittent double peak, a diagnosis of vocal fold paresis was made on stroboscopic examination. This finding could be hypothesized to be the result of technical flaws during the EGG procedure.

4.3.4. Various laryngeal pathologies associated with ***left sided double peak*** on the EGG waveform

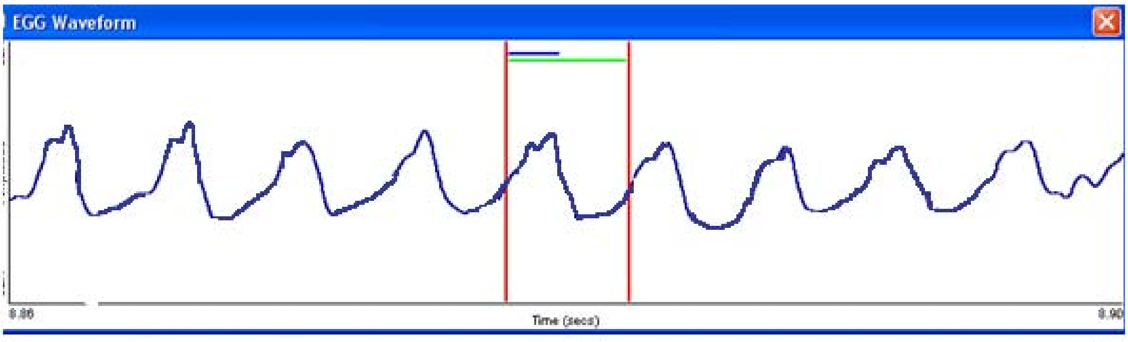


Figure 4.7, Morphological representation of EGG waveform with left sided notch/double Peak

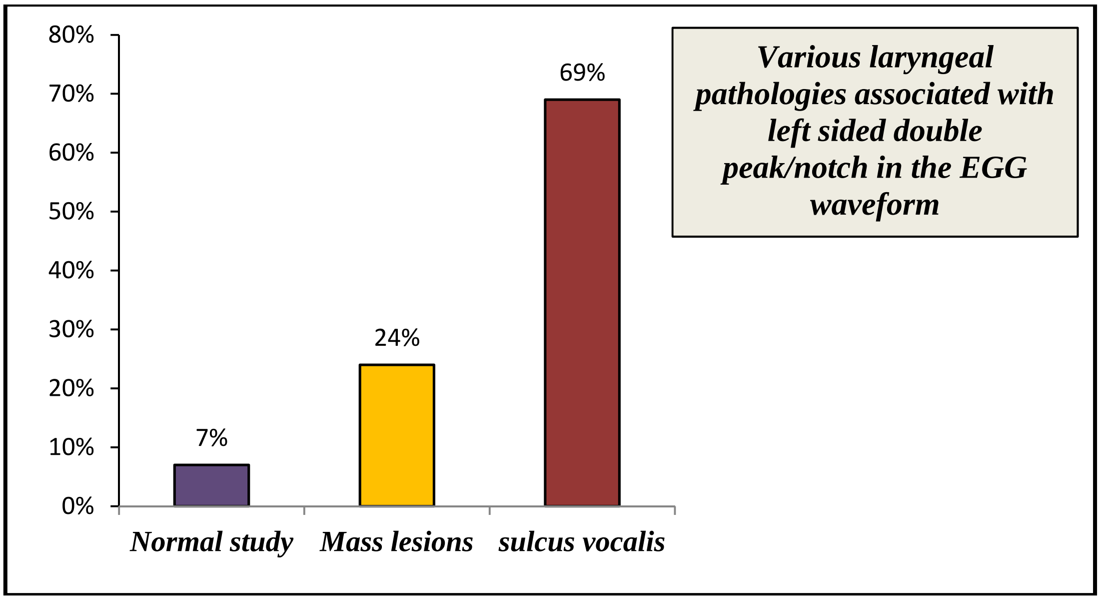


Figure 4.8, Various laryngeal pathologies associated with left sided/notch double peak in the EGG waveform

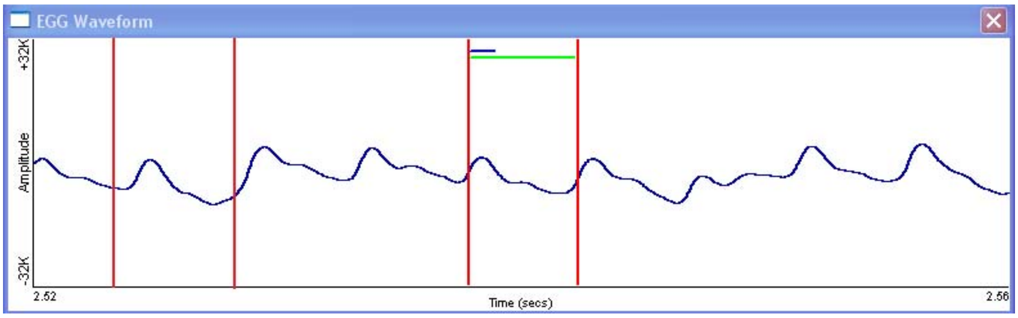
Left sided notch/double peak in the EGG waveform was seen in a total of 26 of the overall 517 participants. Figure 4.7 depicts the graphical representation of various laryngeal pathologies that were associated with left sided notch/double peak. Stroboscopic examination on these participants revealed, 69% of them to have sulcus vocalis, 24% to have nodular changes, polyps, cysts and other edematous lesions and the rest 7% to have normal vocal cord structure and functioning.

In the present study, 69% (18/26) of participants with left sided notch/ peak were found to have pathologic type of sulcus on stroboscopic examination. Presence of pathologic sulcus was confirmed by the criteria of absent mucosal wave and stiffened mucosa resulting in high pitched breathy voice. This finding from the present study is supported by the observations of Lim etal (2008) who reported the appearance of left sided notch/depression in the adductory phase of EGG waveform in cases of sulcus. Further, they reported that the exact place of the pit shaped notch/undulation depends on EGG signal depends on the location of sulcus deformity. This notch like undulation in the waveform could be speculated to occur as a result of the groove that creates a depression/notch during the normal adductory process.

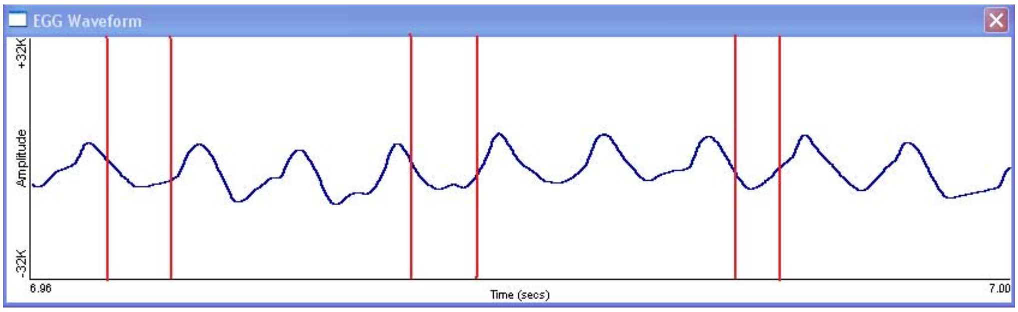
24% (6/26) of patients with left sided double peak were found to have early nodular changes, nodules, vocal polyps, cysts and other mass lesions. This finding can be supported by reports in literature that reveal evidences of double peaks/notches in case of mass lesions (Motta et al., 1990; Sreedevi et al., 1993). Further, the present finding indicated the notch/peak to be inclined slightly towards left side in the adductory phase implying that it was observed in the immediate beginning of the adductory phase of vibratory cycle. Hence, it can be concluded that the exact anatomical position of these mass lesions can determine if notches in the EGG waveform will be left/right sided (at the specific start/end portions of the adductory phase).

In routine clinical practice, the presence of double peak/notched appearance on the EGG waveform generally is assumed to signal any form of mass lesion. The present study highlights the fact that notch/double peak appearances should be thought of as pit shaped/grooved depressions too signalling conditions other than mass lesions (e.g.; sulcus vocalis). They should not be routinely interpreted as mass lesions alone. In addition to EGG, other factors such as case history details, results of other voice evaluations along with perceptual analysis should be considered before arriving at a diagnostic conclusion. For the purpose of differential diagnosis it can be further noted that, in cases of mass lesions, a typical low pitched hoarse voice is present and in cases of sulcus, a high pitched breathy voice is predominant.

4.3.5. Various laryngeal conditions associated with *periodic irregularities* in the EGG waveform



(a)



(b)

Figure 4.9 (a,b), Morphological representations of two different EGG waveforms showing irregularities in periodicity

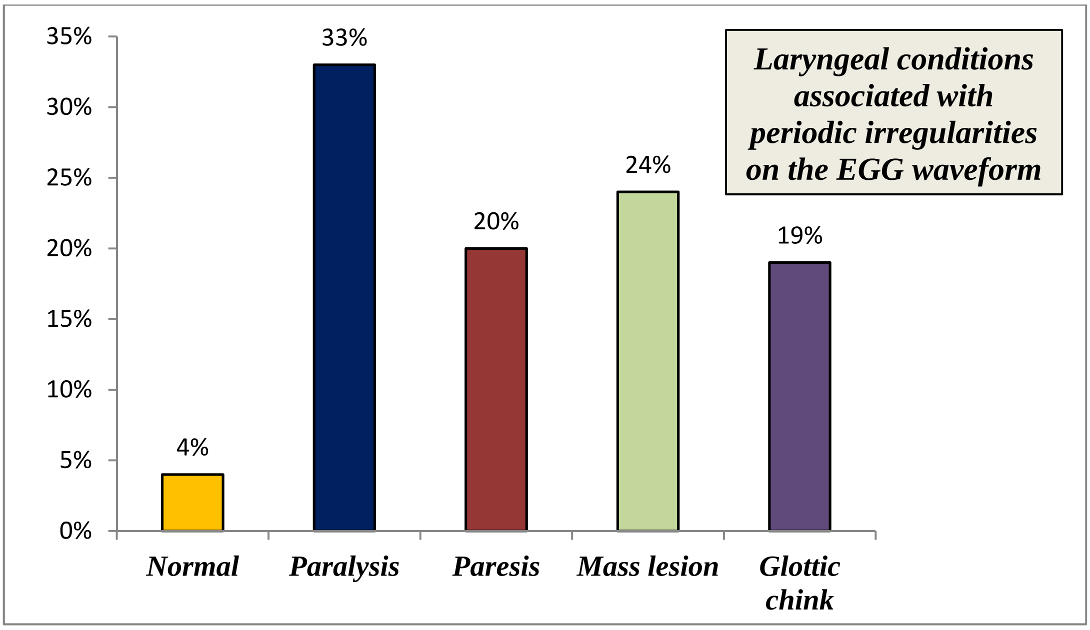


Figure 4.10, Various laryngeal pathologies associated with irregular periodicities

Regularity, or periodicity, of vocal fold vibration in this context, can be defined as the exact replication of a spatial-temporal pattern. Thus, irregularity and aperiodicity refer to any change of this pattern over time (Figure 4.8). Irregular periodicity in the EGG waveform thus was characterized by peaks with relatively same wave amplitude and morphology but varying in terms of periodic/temporal phases (asymmetries in durations of closing, closed, opening and open phases). Fuzziness in periodicity was the main feature. A total of 21 of the 517 cases were found to have EGG waveforms with irregularity in periodicity. Figure 4.9 depicts the various laryngeal pathologies that were associated with aperiodic EGG waveforms.

33% (7/21) of participants with irregular periodicity in the EGG waveforms were found to have unilateral vocal fold paralysis on stroboscopic examination. This finding is in consonance with that of Bonilha and Deliyski (2007) who reported unilateral laryngeal nerve paralysis to be one of the main voice disorders to be commonly associated with periodic irregularities. Further, they reported that irregularity of vocal fold vibration is typically the result of an imbalance of mass/tension between the right and left vocal folds and to also be caused by inconsistent/ inadequate airflow driving the vibration. Hence, aperiodic EGG waveforms in cases of vocal fold paralysis can be attributed to the imbalances in tension and mass (bulk) between the two vibrating cords and to certain inconsistencies in airflow.

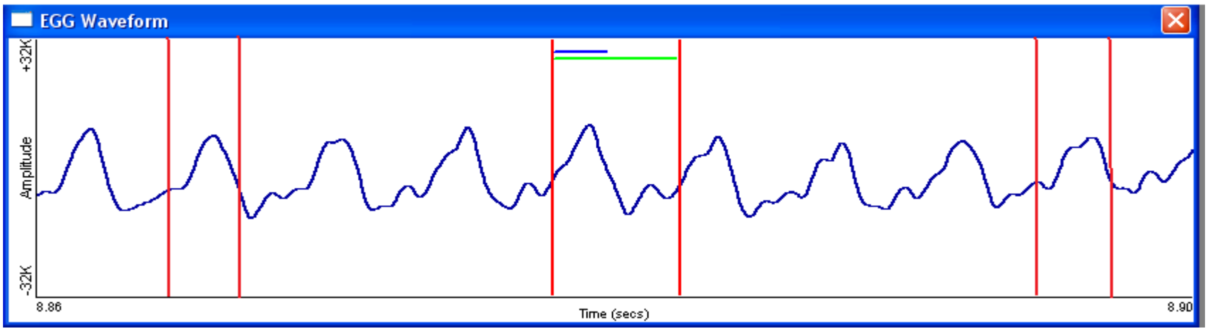
20% (4/21) of participants with irregularity in periodicity in their EGG waveforms were found to have vocal fold paresis on stroboscopic examination. This could be possibly due to alterations in vocalis muscle tension. In addition, since paresis is generally a flaccid condition, periodic normal vibratory patterns could not be much possible owing to fatigue in the laryngeal muscles.

24% (5/21) of participants with periodic irregularities in the EGG waveform were found to have mass lesions on stroboscopy (majorly polyps, cysts and edematous lesions).

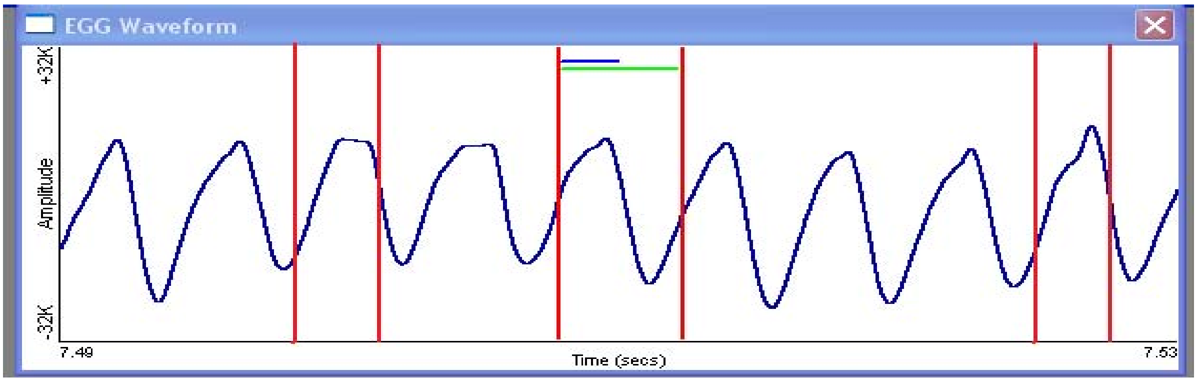
This again could be owing to alterations in muscle mass and tension of the affected vocal cord. This finding of aperiodic vibrations is in support with the reports of Bonilha etal (2007) and Altman (2007). In two (2/5) participants with irregular periodicities, reinkes edema was the diagnosis on stroboscopic examination. This finding is in consonance with the reports of Motta etal (1990), who reported irregular EGG waveforms in rinkes edema patients owing to the scattered edematous lesion interfering sporadically with normal vibratory patterns.

19% (4/21) of participants with irregular periodicity in the EGG waveform were found to have glottic chink on stroboscopic examination. Two participants each were found to have a wide spindle shaped glottic chink and irregular glottic chink with excess breathy voice. In excess breathy voice, especially in cases of irregular glottic chink, mucosal wave will be inconsistent accompanied by excess air egress. This could lead to altered/asymmetric vibratory patterns; pitch and amplitude perturbations in turn leading to aperiodic EGG waveforms. Another possible reason for aperiodic EGG waveform could be the other extrinsic variables not monitored adequately during EGG procedure. Some of these could be: faulty placement of electrodes, excess fat tissue in the neck leading to false negative errors, poor quality of the signal obtained, artefacts introduced into the signal by head movements or vertical shifts of the larynx and so on.

4.3.6. Various laryngeal conditions associated with ***impaired cycle-cycle replicablity*** in the EGG waveform



(a)



(b)

Figure 4.11 (a,b), Morphological representations of two different EGG waveforms with irregular cycle-cycle replicablity

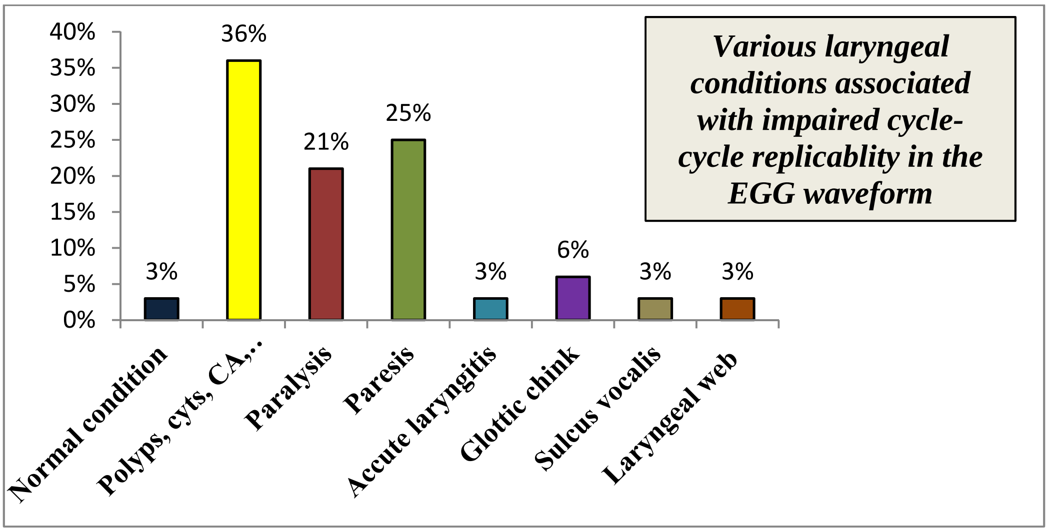


Figure 4.12, Various laryngeal pathologies associated with irregular cycle-cycle replicablity

As depicted in Figure 4.10, the EGG waveforms with asymmetric cycle/cycle replicablity were characterized by successive cycles of the waveform with irregular morphologies (either in terms of double peaks in some cycles, amplitude asymmetries, tremors and/ irregular peaks in some cycles etc). This was seen in a total of 33 cases of the overall 517. Figure 4.11 represents the hierarchy of various laryngeal conditions that had EGG waveforms with impaired cycle-cycle replicablity.

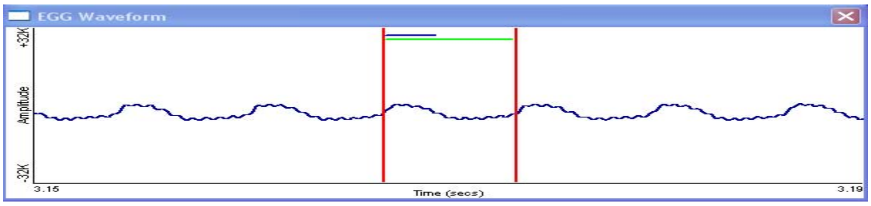
36% (12/33) of participants with impaired cycle-cycle replicablity were found to have polyps, initial carcinomas, cysts, edematous lesions and early nodular changes on stroboscopic examination. This finding is in consonance with that of Bonilha etal (2007), who reported irregular vibrations to be associated with polyps, cysts and unilateral carcinomatous lesions; owing to the altered mass-tension relationship of the affected vocal cord. In addition, the presence of pedunculated polyps that sporadically interfere with vibration may give rise to irregular patterns on the EGG waveform.

21% (7/33) and 25% (8/33) of participants with irregular replicablity of morphological patterns on EGG were found to have vocal fold paralysis and paresis respectively on stroboscopic examination. Presence of this pattern in vocal fold paralysis and paresis could be owing to altered pliability of one vocal cord relative to the other; fatigue associated with the affected cord and altered mass-tension balance between the cords.

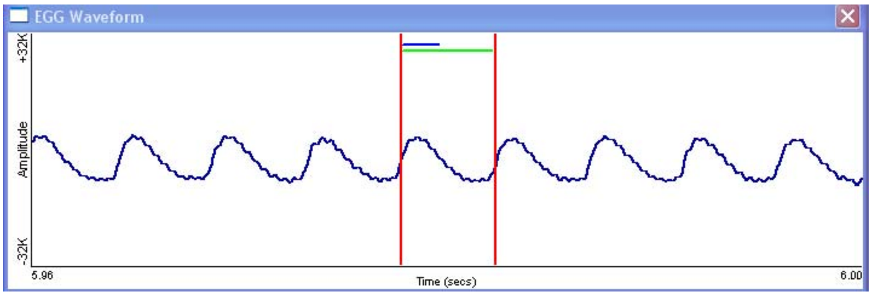
This pattern of irregular morphological replicablity was seen in very low percentages in cases of acute laryngitis (3%), glottic chink (6%), normal condition (3%), sulcus vocalis (3%) and laryngeal web (3%). Evidence of such patterns in cases of laryngeal infections is in support of the findings by Sreedevi etal (1993) who reported fuzziness/irregular EGG patterns in cases of laryngitis. The reason behind such a finding could be attributed to the alterations in the passage of current being affected erratically by histopathological changes in the larynx yielding irregular EGG waveforms.

Presence of this irregular EGG pattern in cases of glottic chink and normal condition could be owing to other extrinsic variables that affect the EGG waveform (faulty electrodes placement, altered skin-electrode resistance, presence of excess fat tissue in neck and so on). This EGG pattern was found in one participant who had severe pathologic sulcus. In this case, such a finding could be attributed to the severe pathologic sulcus groove altering the mass-tension balance and generating asymmetrical vibratory patterns between the two cords. In cases of laryngeal web, the presence of such wave pattern could be associated with the altered mass-tension relationship of both the cords being affected by the anterior web.

4.3.7. Various laryngeal conditions associated with *tremulous pattern* on the EGG waveform



(a)



(b)

Figure 4.13(a,b), Morphological representations of two different EGG waveforms with tremulous Patterns

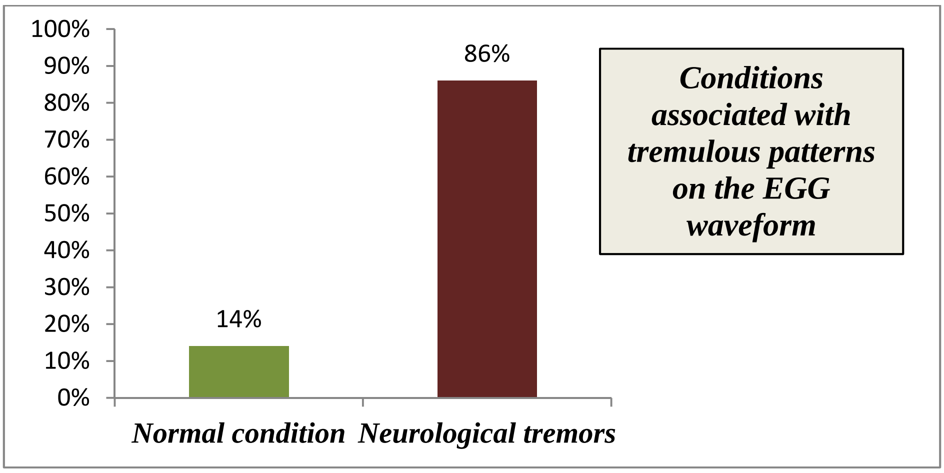


Figure 4.14: Laryngeal conditions associated with tremulous EGG wave morphologies.

In the present study, seven of the total 517 cases, had tremulous vibratory patterns on the EGG waveform (Figure 4.12). Figure 4.13 represents the laryngeal conditions associated with tremulous EGG wave morphologies. Tremulous EGG wave pattern was characterized by recurrent and mostly symmetric jerks/perturbations on the waveform. On stroboscopic examination 86% (6/7) of these patients with tremulous vibrations were diagnosed as either essential voice tremors/ Parkinson tremors and 14% (1/7) of these participants was found to have normal vibrations. Essential voice tremor, characterized by the voice's regular trembling (4–8 times/second) vibrations is generally observed in the opening movement of vocal cords and up-and-down movement of the larynx (Omori, 2009). These regular tremulous vibrations, symmetrically altering the electrical conductance-resistance of the EGG waveform could have resulted in such tremulous patterns. In one case of normal vocal cord vibrations on stroboscopic examination, tremulous EGG pattern was obtained. This was a case of psychogenic dysphonia, wherein there was intentional production of tremulous phonation, with absence of tremors on stroboscopic examination.

4.3.8. Various laryngeal conditions associated with *prolonged open time* in the EGG waveform

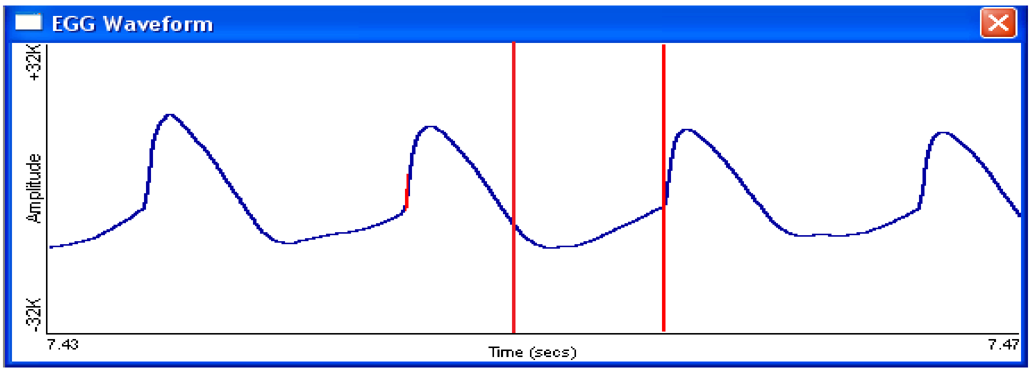


Figure 4.15, Morphological representation of EGG waveform with prolonged open phase

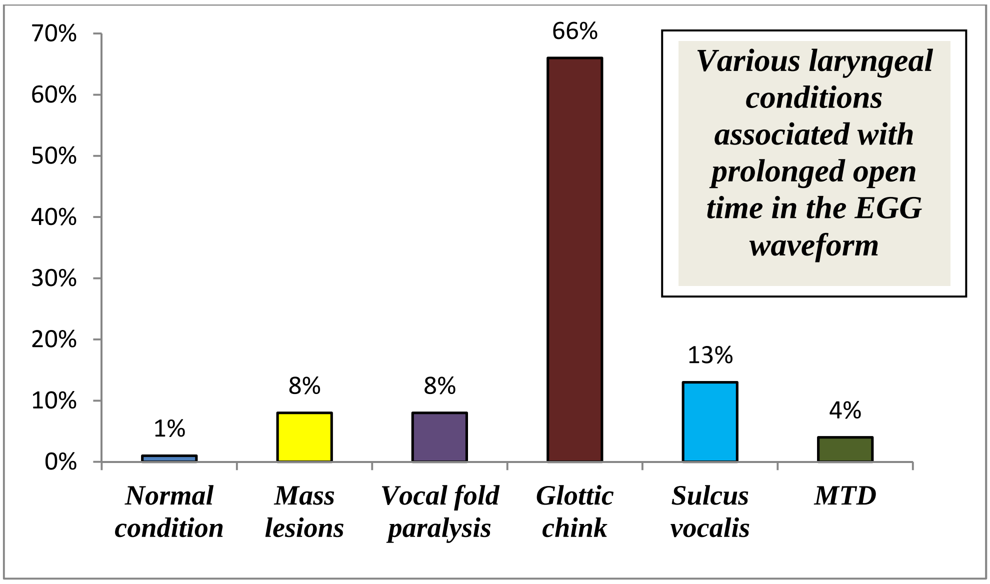


Figure 4.16, Various laryngeal pathologies associated with prolonged open time in the EGG waveform

In the present study, 111 of the total 517 participants had prolonged open time (Fig 4.14) in the EGG waveform. Figure 4.15 represents the various laryngeal conditions associated with prolonged open time in the EGG waveform. As can be seen from Figure 4.15, maximum incidence (58/111) of prolonged open time in the EGG waveform was seen in cases of glottic chink (anterior, spindle shaped and posterior glottic chink). This is in consonance with the findings of Fourcin (1981), Abberton etal (1989) and Mitra (2004) who reported small closure peaks and extended open phases (allowing more air to escape in each cycle) of EGG waveform in breathy voices (cases of glottic chink). Additionally, in a few synchronized EGG-stroboscopic studies, instances of glottic chink on stroboscopy have been found to be associated with extended open phases in the EGG waveform (Anastaplo & Karnell, 1988; Roch etal, 1990).

In 13% (14/111) of participants with a prolonged/extended open phase pattern in the EGG waveform, sulcus vocalis was the underlying condition. In all these participants, sulcus was pathologic in nature, with predominant spindle shaped glottic chink; characterized by high pitch-breathy voices. It has been reported that specially in cases of pathologic sulcus, there is an impairment of glottal closure and incomplete compensation (Lim etal, 2009). This might be the probable cause for the appearance of prolonged open time in the EGG waveforms.

As can be inferred from Figure 4.15, prolonged/extended open phase was seen in 8% (9/111) of participants each with vocal fold paralysis and mass lesions. The present result in cases of vocal fold paralysis is in support of the findings by Zagolski (2009) who reported prolonged/extended open phases in cases of vocal fold palsy. Further, this finding can be explicated by the fact that, there is often an incomplete/impaired compensation in cases of paralysis hampering the normal closure patterns. This is reflected as linear/spindle shaped glottic chink which leads to prolonged open phases on the EGG waveform.

Prolonged open phase was seen in 8% (9/111) of participants with vocal fold mass lesions. Among these 9 participants, six of them had early nodular changes and the rest three were found to have polyps and cysts. In cases of early nodular changes, there are evident changes on the superficial vocal fold layers with no apparent mass like structure. Owing to these nodular changes, normal vibratory patterns might be impaired leading to excess air egress and extended open phases on the EGG waveform. In polyps and cysts, disruption of vocal fold vibration and phase closure due to the mass, leads to phase asymmetries and excess air venting out. This reflects as extension of open phases on the EGG waveform.

4% of participants (5/111) with prolonged open phase were found to have primary type I and type III MTD features on stroboscopic examination. These were characterized by posterior glottic chink and anterior-posterior constriction; thereby reducing the space between epiglottis and arytenoid prominences and producing glottic chink patterns. This might have led to the extension/prolongation of open phases on the EGG waveform. In one participant with prolonged open time in the EGG waveform normal vocal cords was observed. This could most probably be owing to certain flaws associated with the technical procedure during the EGG recording.

4.3.9. Various laryngeal conditions associated with *prolonged closed time* in the EGG waveform

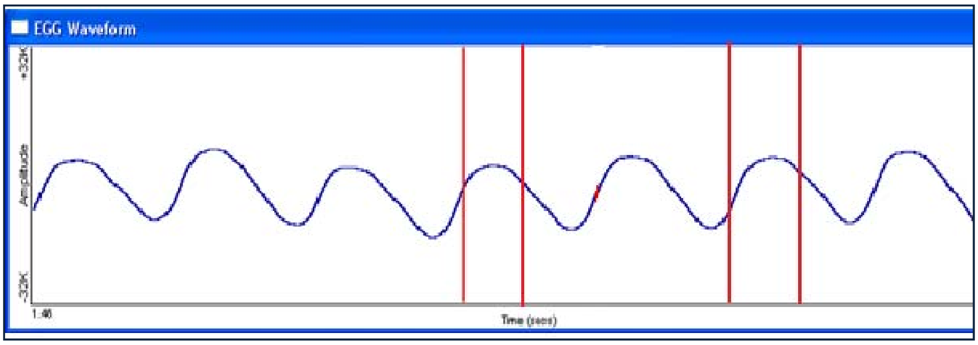


Figure 4.17, Morphological representation of the EGG waveform with prolonged closed phase

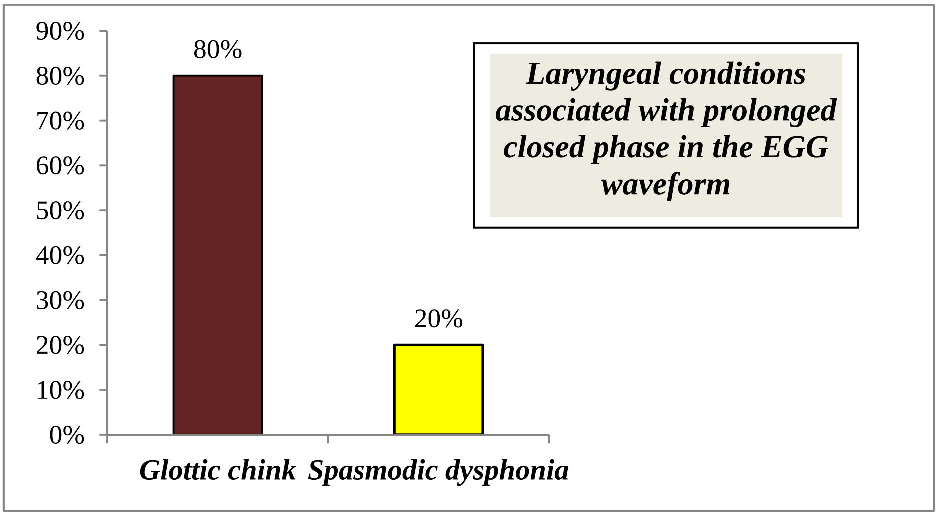


Figure 4.18, Laryngeal conditions associated with prolonged closed phase in the EGG waveform

In the present study, 10 participants of the overall 517 were found to have prolonged/ extended closed phase (Figure 4.16) in the EGG waveform. Figure 4.17 demonstrates the hierarchy of laryngeal conditions that had prolonged closed phases in the EGG waveform. As can be seen (Figure 4.17), glottic chink and spasmodic dysphonia are the two conditions that were found to have prolonged/ extended closed phase.

Spindle shaped/ linear glottic chink was the laryngeal condition seen in 80% (8/10) of the cases with prolonged closed phase in the EGG waveform. This result is in support of the findings by Sreedevi et al (1993) who reported the presence of prolonged closed phases in case of glottic chink. The reason behind such a finding can be explained in the following manner. In cases of glottic chink, (specifically wider spindle shaped/linear glottic chink) the vocal folds are separated posterior or they don't have contact throughout their entire length which results in continuous air escape. Hence, the vocal folds remain in medial /closed position until the necessary sub glottal air pressure is built up for phonation resulting in prolonged closed phase on the EGG waveform.

Findings from the present study portray that in cases of glottic chink, prolongation of either open or closed phases can be seen, but nevertheless, incidence of prolonged open phases is seen in large numbers. Hence, in making an inference based on prolonged open/closed phases on the EGG waveform, it is much essential to look at the case history details and perceptual evaluations.

In two participants with prolonged closed phases of the EGG waveform, a diagnosis of spasmodic dysphonia on stroboscopy was made. Spasmodic dysphonia in both these participants was adductory in nature, characterized by strained, strangled and tensed phonation and spasms. This might have led to the emergence of extended closed phases on the EGG waveform. There are reports in literature that report prolonged closed phases in case of tensed/strained voices, thereby supporting the present observation (Van Michel, 1967; Kitzing, 1979; Childers, 1984 & Baken, 1988**).**

4.3.10. Laryngeal conditions associated with *prolonged closing time* in the EGG waveform

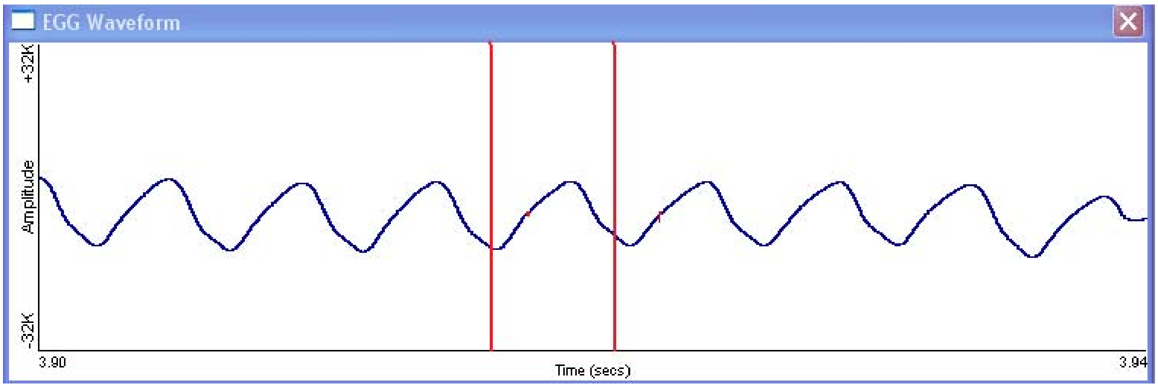


Figure 4.19, Morphological representation of an EGG waveform with prolonged closing phase

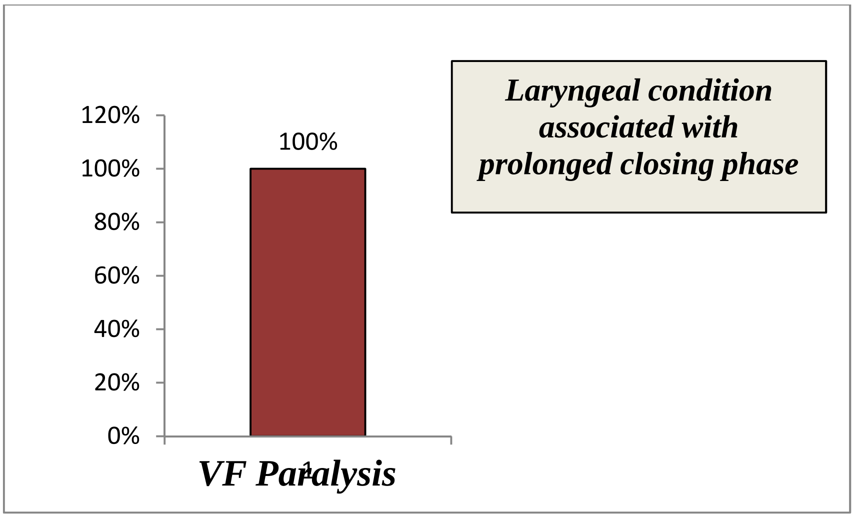


Figure 4.20, Laryngeal condition associated with prolonged closing phase

Prolonged closing phase (Fig 4.18, 4.19) was seen in 21 participants of the overall 517. As can be seen from Fig 4.19, all the participants who had prolonged closing phases in the EGG waveforms were found to have unilateral vocal fold paralysis on stroboscopic examination. This observation can be supported by the findings of Sreedevi et al. (1993) and Zagolski (2009) who reported prolonged closing phases in the EGG waveforms of persons with vocal fold paralysis. This finding can be attributed to the fact that the paralyzed vocal fold is usually in the paramedian position, and hence the healthy vocal cord takes longer time to make contact with the paralyzed cord.

4.3.11. Various laryngeal conditions associated with *prolonged opening time* in the EGG waveform

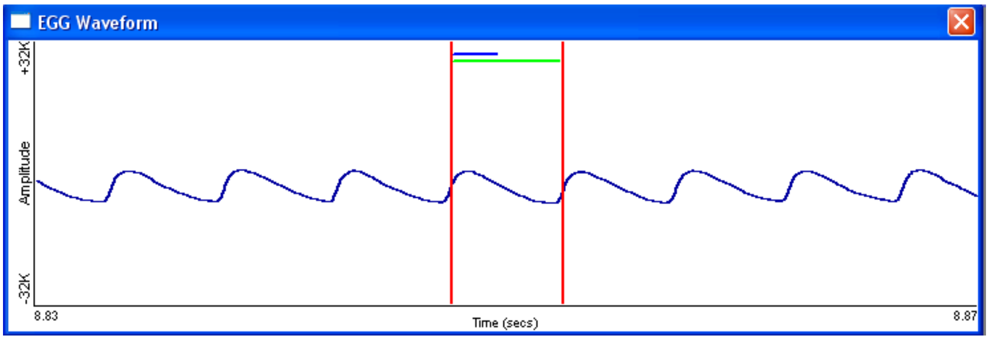


Figure 4.21, Morphological representation of an EGG waveform with prolonged opening time

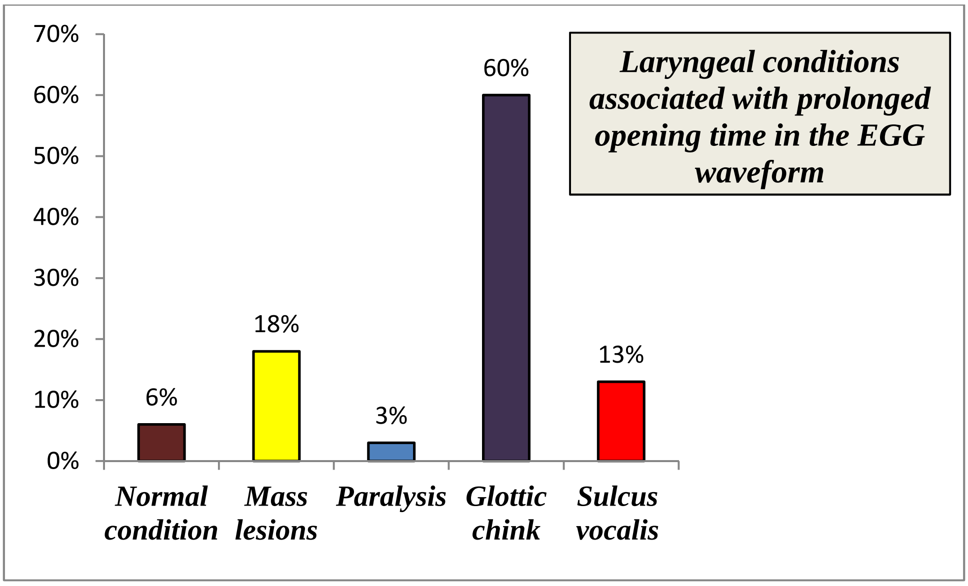


Figure 4.22, Various laryngeal conditions associated with prolonged opening phase

EGG waveforms with prolonged opening phase (Figure 4.20) were seen in 32 of the overall 517 participants. Figure 4.21 represents the hierarchy of various laryngeal conditions that had prolonged/extended opening time in the EGG waveforms. As can be inferred from Figure 4.21, instances of prolonged opening phase were seen maximally in cases of glottic chink (19/32). Incidences of spindle shaped and posterior glottic chink were more compared to anterior glottic chink. This observation can be supported by the findings by Lim etal (2009), who report breathiness or glottic chink to be associated with extended opening times and reduced/abrupt closing times. Further, owing to an incessant air escape in cases of glottic chink (more so with respect to spindle shaped/linear glottic chink), opening phase might be extended. In six participants with prolonged opening phases, the vocal folds were atrophied and bowed leading to spindle shaped glottic chink. This bowing was a result of the impaired tension between the two cords owing to atrophy of the vocalis muscle. This finding can be supported by the observations of Wechsler (1977) and Baken (1992) who reported changes in the opening or closing segments to often signal abnormalities in vocal fold tension.

18% (6/32) of participants with prolonged opening phases in the EGG waveforms were found to have mass lesions on stroboscopic examination. One reason for this could be that, as there is a presence of some mass on the vocal cords, the tension between the cords might be altered leading to variations in the opening phases. Another possible hypothesis could be that the lesions might not have clearly compromised the vibratory patterns mainly by their characteristics (consistence, exact site of lesion etc).

13% (4/32) of the participants with prolonged opening phases were found to have sulcus vocalis on stroboscopic examination. This observation is in consonance with the findings of Lim et al. (2009) who reported the presence of EGG waveforms with abrupt/short closing phases and prolonged opening phases in cases of sulcus.

6% (2/32) of participants with prolonged opening phases in the EGG waveform had normal vocal structure and function as evidenced on stroboscopy. These two participants were females, and a slight posterior glottic chink was noticed. But, as posterior glottic chink is normal in case of females, a diagnosis of normal condition was inferred. This petite posterior glottic chink might have led to the occurrence of prolonged opening phase in the EGG waveforms.

In one subject with prolonged opening phase, a diagnosis of unilateral vocal fold paralysis was made on stroboscopic examination. In majority of the cases with vocal fold paralysis, either prolonged closing/open phase in the EGG waveforms was noticed. This finding of prolonged opening phase could be owing to certain extrinsic variables during the EGG procedure which needs to be explored further.

4.3.12. Laryngeal conditions associated with *low amplitude* of the EGG waveform

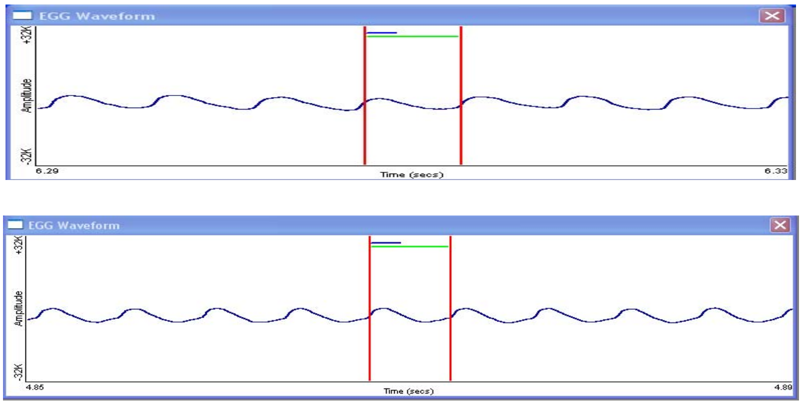


Figure 4.23, Morphological representations depicting reduced amplitude in two different *EGG* waveforms

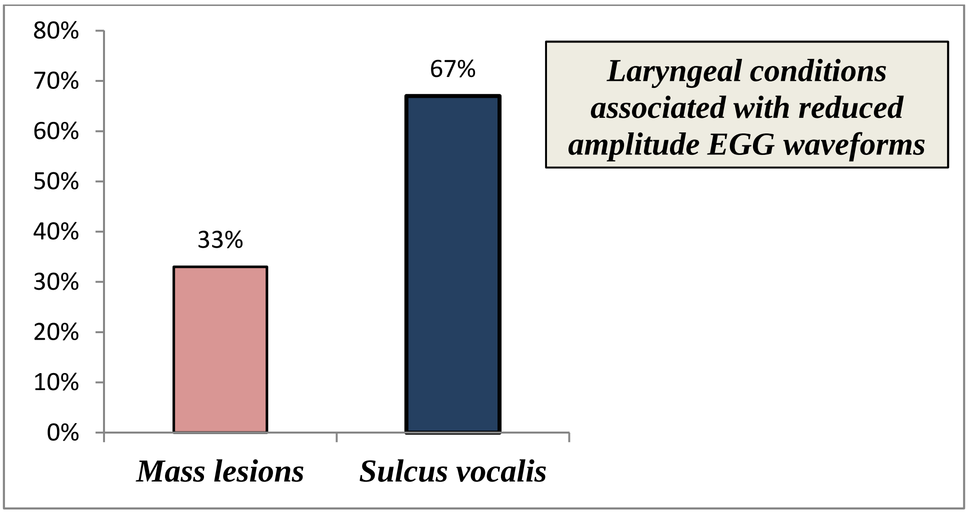
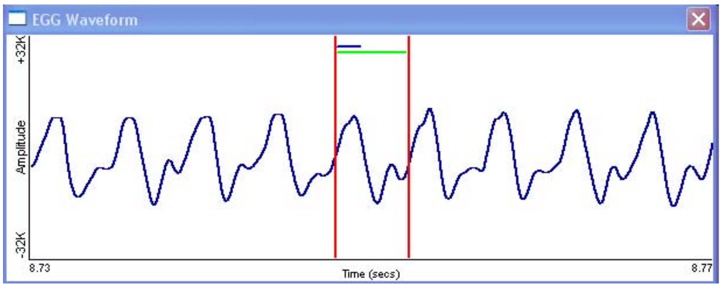


Figure 4.24, Laryngeal conditions associated with reduced amplitude EGG Waveforms

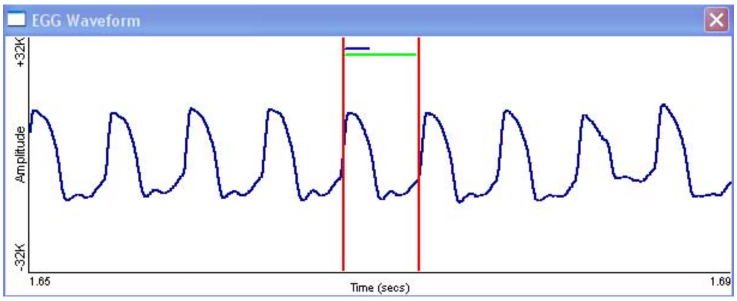
In three participants of the overall 517, EGG waveforms with weakened and low/reduced amplitude (Figure 4.22) were obtained. Figure 4.23 depicts the graphical representation of the laryngeal conditions associated with reduced amplitude in the EGG waveforms. As can be seen from Figure 4.23; in 67% (2/3) of the participants with prolonged opening phase, a diagnosis of sulcus vocalis was made on stroboscopic examination. This finding is in consonance with the study by Lim et al (2009) who reported the presence of weak/low amplitude EGG waveforms in cases of sulcus due to impairment of glottic closure and incomplete compensation.

In one participant with rinkes edema, very low amplitude and weakened EGG waveform was obtained. Under this circumstance, it is possible to hypothesize that, incomplete compensation and feeble vibratory patterns might have led to such an EGG morphological pattern.

4.3.13. Laryngeal conditions associated with *bitonal waves* in the EGG waveform



(a)



(b)

Figure 4.25(a,b), Morphological representation of 2 different EGG waveforms with bitonal waves

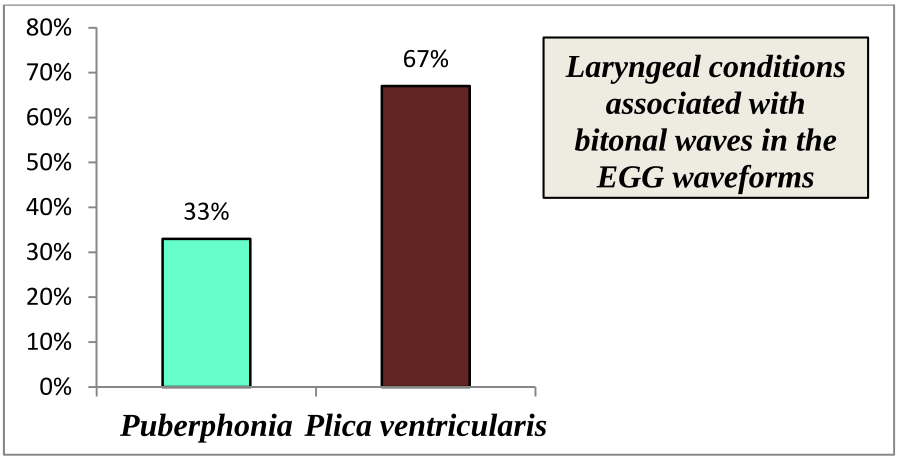


Figure 4.26, Laryngeal conditions associated with bitonal/biphasic waves in the EGG Waveform

Three participants of the overall 517 were found to have biphasic/bitonal EGG waveforms (Figure 4.24). Figure 4.25 depicts the graphical representation of the laryngeal conditions associated with bitonal/biphasic EGG waveforms. As can be seen, two participants and one participant of the participants with bitonal/biphasic waves were found to have dysphonia plica ventricularis and puberphonia respectively on stroboscopic examination. Both these conditions (puberphonia and plica ventricularis) manifest with the phenomenon of diplophonia. Hence, this observation is in consonance with the findings of Dejonckere et al (1983) who reported the presence of abnormal bitonal/biphasic EGG waveforms in cases of diplophonia. This phenomenon of bitonality is further explained in the following manner. In cases of diplophonia, both the true and the false cords may take part in vocalization, giving rise to a double voice. In this event, the false vocal cords provide a somewhat lower pitch than the true folds, resulting in bitonality in the EGG waveforms (Greene, 1975).

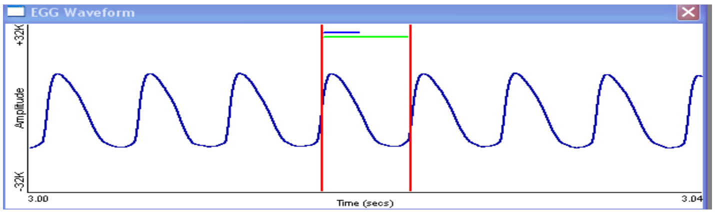
Table 4.1 summarizes the various EGG waveform patterns and the associated stroboscopic findings that were obtained in the experimental group in the present study.

Table 4.1

Summary of the EGG waveform patterns and the associated major stroboscopic findings in the ***experimental group***

<table>
<tr><th><u>EGG waveform pattern</u></th><th><u>Associated major stroboscopic findings (in percentage)</u></th></tr>
<tr><td>

1. *Normal EGG waveform (127/517)*

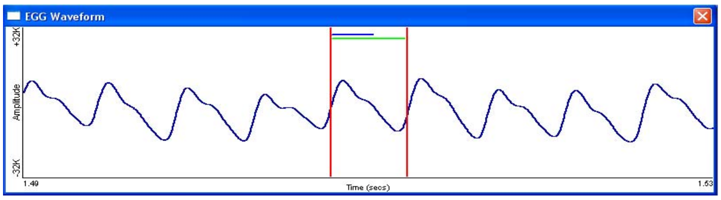


</td><td>

- Normal laryngeal structure and functioning (39%)
- MTD (19%)
- Sulcus vocalis (9%)
- Early nodular changes (9%)

</td></tr>
<tr><td>

2. *Right sided notch/double peak in the EGG waveform (91/517)*



</td><td>

- Early nodular changes (45%)
- Developed nodules (23%)
- Polyps (13%)
- Edematous lesions (9%)

</td></tr>
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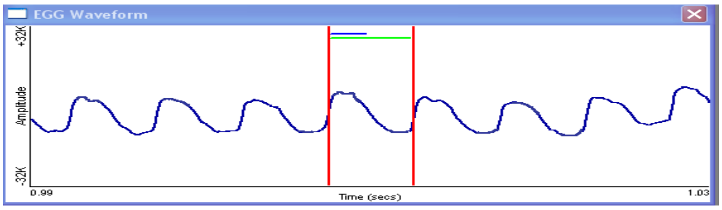
3. *Intermittent double peak in the EGG waveform (32/517)*



</td><td>

- Polyps (67%)
- Early nodular changes (17%)
- Developed nodules (10%)

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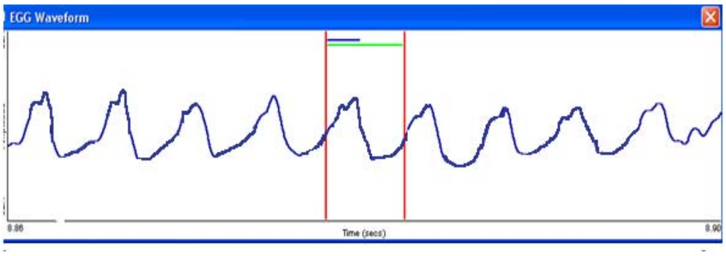
4. *Left sided notch/double peak in the EGG waveform*

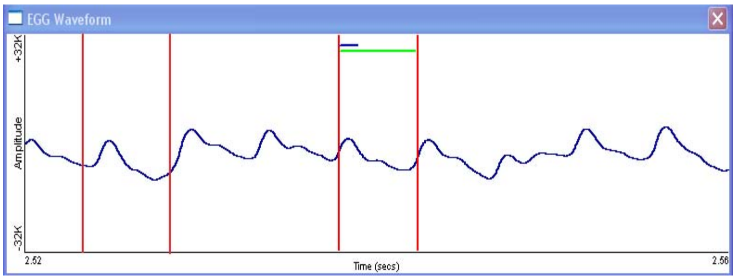
(26/517)



- Sulcus vocalis (69%)
- Mass lesions (24%)

5. *EGG waveform with irregular periodicity*

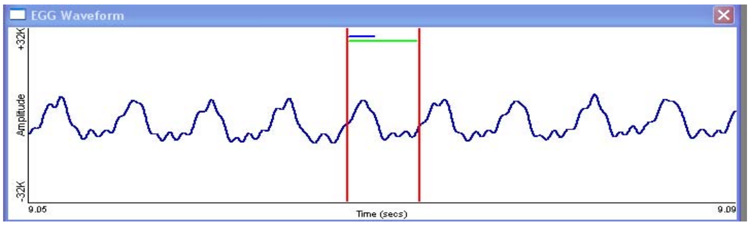
(21/517)



- Unilateral Paralysis (33%)
- Paresis (20%)
- Polyps, cysts and edematous lesions (24%)
- Irregular and spindle shaped glottic chink (19%)

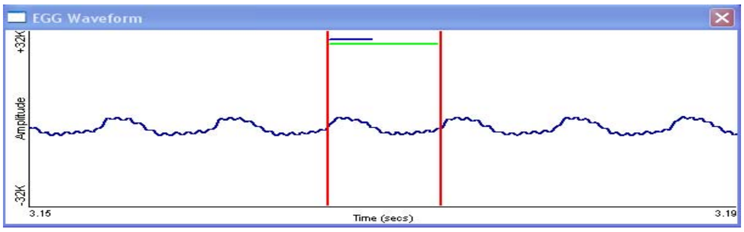
6. *EGG waveform with impaired cycle-cycle replicablity*

(33/517)



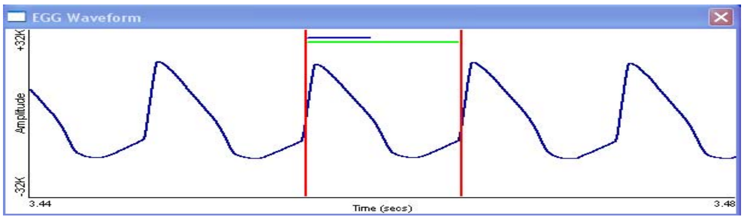
- Polyps, cysts, edematous lesions and initial carcinomas (36%)
- Paresis (24%)
- U/L paralysis (21%)

7. *EGG waveform with a tremulous pattern (7/517)*



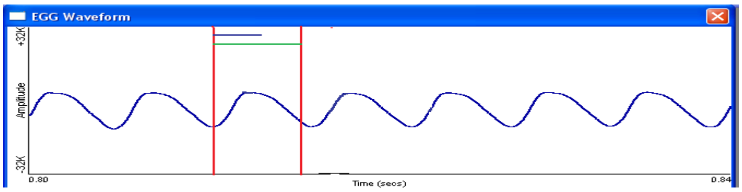
- Neurological tremors (86%)

8. *EGG waveform with prolonged open phase (111/517)*



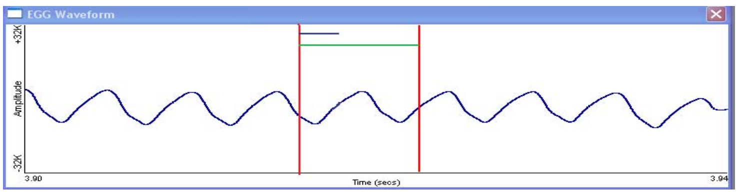
- Anterior, spindle shaped and posterior glottic chink (66%)
- Sulcus vocalis (13%)

9. *EGG waveform with prolonged closed phase (10/517)*



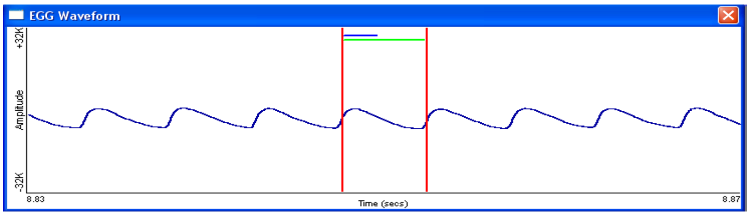
- Glottic chink (80%)
- Spasmodic dysphonia (20%)

10. *EGG waveform with prolonged closing phase (21/517)*



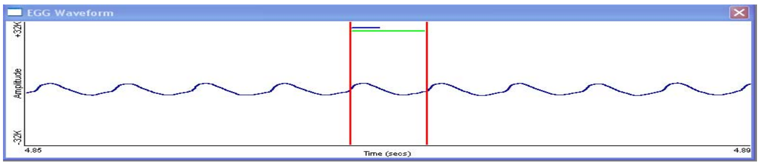
- Vocal fold paralysis (100%)

11. EGG waveform with prolonged opening phase (32/517)



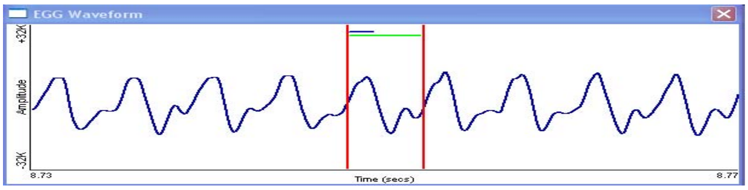
- Glottic chink (60%)
- Mass lesions (18%)
- Sulcus vocalis (13%)

12. EGG waveform with reduced/low amplitude (3/517)



- Sulcus vocalis (67%)
- Mass lesions (33%)

13. EGG waveform with bitonal/biphasic waves (3/517)



- Plica ventricularis (67%)
- Puberphonia (33%)

4.4. Association of the EGG waveform with stroboscopy in the control group

A total of 101 phononormic individuals were recruited under the control group based on a checklist devised (Appendix 1). These 101 phononormic participants were first made to undergo stroboscopic evaluation followed by the EGG procedure. Under the stroboscopic evaluation it was found that some of these phononormic participants had certain MTD features or small posterior glottic chink. Since, posterior glottic chink is a normal phenomenon in females and MTD like features were surfacing in some participants with no reported overt physical signs and symptoms, they were considered to be under the normal curve itself. So, an overall conclusion of either normal study/MTD/posterior glottic chink was made in these phononormic participants.

On applying the Chi-square test of association, a statistically significant association (p = 0.001) was found to exist between the overall stroboscopic results and the EGG wave patterns. On applying the Cramers-V test to measure the extent of association, a moderate association level (p = 0.524) was found to exist between the overall results of stroboscopy and EGG.

4.4.1. EGG waveform patterns present in conditions of *normal laryngeal structure and functioning*

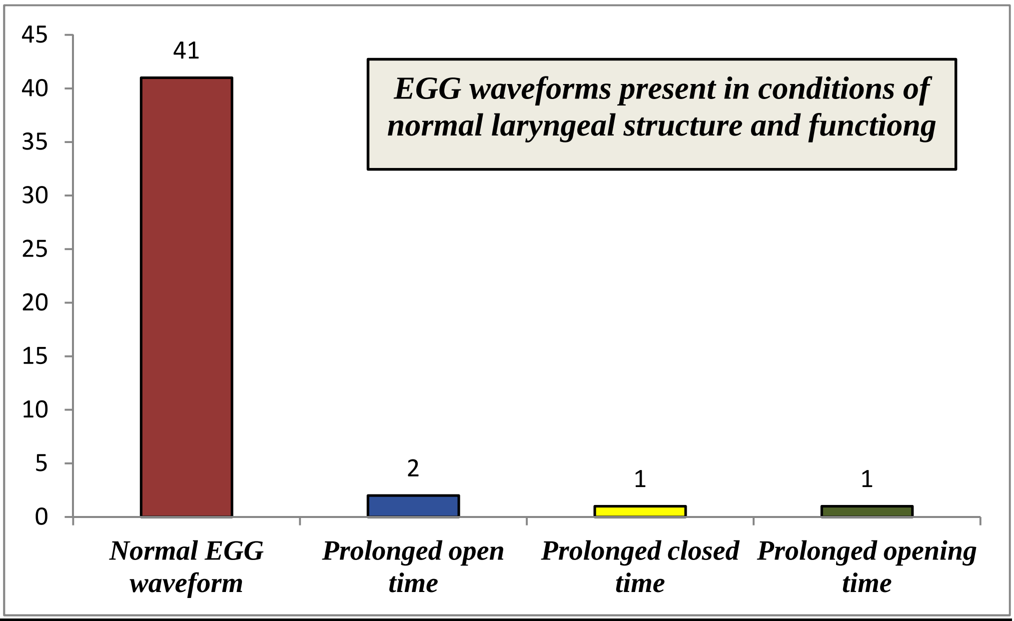


Figure 4.27, EGG waveform patterns present in normal conditions of laryngeal structure and functioning

A diagnosis of normal laryngeal structure and functioning was made in 45 participants of the total 101 phononormic individuals in the control group. Figure 4.26 depicts the various EGG waveform types that were obtained in these participants with normal laryngeal structure and functioning. As can be inferred from Figure 4.26, normal EGG waveforms were obtained in 41 participants, in 2 participants' prolonged open time was noticed and in 1 participant each, prolonged closed time and prolonged opening time were observed. The finding of normal EGG waveforms in majority of participants (41/45) with normal laryngeal structure and functioning is obvious as normal vibratory patterns will reflect as normal waveforms on EGG also. Other patterns of prolonged open time, closed time and opening time in a few participants (4/45) could be owing to the extrinsic variables during the EGG procedure that needs to be explored further and monitored. A few of these possibly are: instances of excess mucous collection/ sudden throat clearing/ sudden cough during the EGG procedure that might have triggered changes in the waveform patterns.

4.4.2. EGG waveform patterns present in conditions of ***normal laryngeal structure with a minute posterior glottic chink***

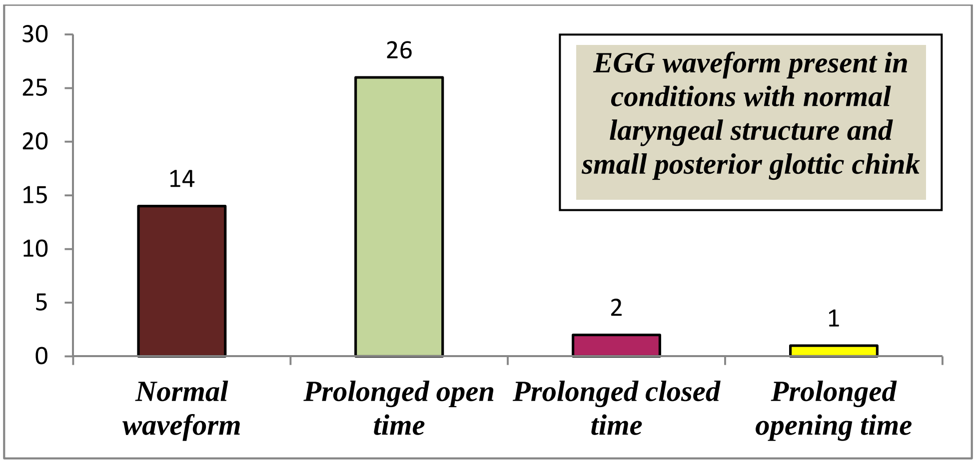


Figure 4.28, EGG waveform patterns present in conditions of normal laryngeal structure and a small posterior glottic chink

On stroboscopic examination, a diagnosis of normal laryngeal structure with a small posterior glottic chink was made in 43 of the 101 phononormic participants in the control group. Figure 4.27 depicts the various EGG waveform patterns present in the condition of normal laryngeal structure with a small posterior glottic chink. As can be seen (Figure 4.27), 14 of 43 phononormic individuals who had small posterior glottic chink were found to have normal EGG waveforms. All these 14 participants were females. As posterior glottic chink is a normal condition seen in females (Sodersten & Lindestad, 1991), the vibratory patterns might not have been much disturbed leading to normal EGG waveform patterns.

In 26 (26/43) participants with small posterior glottic chink, prolonged open time was the observed EGG waveform pattern. This finding of prolonged open phase in case of glottic chink is in consonance with the studies by Fourcin (1981), Abberton et al. (1989) and Mitra (2004) who report small closure peaks and extended open phases (allowing more air to escape in each cycle) of EGG waveform in breathy voices (cases of glottic chink). Additionally, in a few synchronized EGG-stroboscopic studies, instances of glottic chink on stroboscopy have been found to be associated with extended open phases in the EGG waveform (Anastaplo & Karnell, 1988; Roch et al, 1990).

Two participants with posterior glottic chink were found have prolonged closed phase as the EGG waveform pattern. This observation can be supported by the findings of Sreedevi et al. (1993) who reported prolonged closed phase in cases of glottic chink. In one participant with posterior glottic chink, EGG waveform with prolonged opening phase was observed. This could possibly be the result of incessant air escape in cases of posterior glottic chink leading to the perception of extended opening phase on the EGG waveform.

4.4.3. EGG waveform patterns present in conditions of *posterior falling epiglottis*

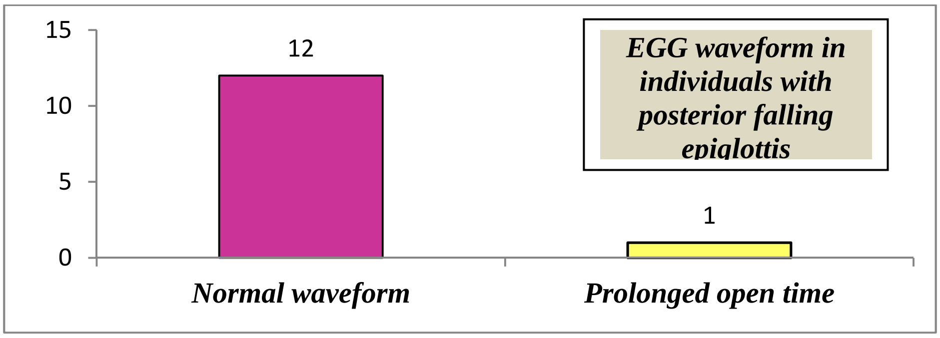


Figure 4.29, EGG waveform patterns in conditions of posterior falling epiglottis

On stroboscopic examination, 13 of the 101 phononormic individuals were found to have posterior falling epiglottis. Figure 4.27 depicts the EGG waveform patterns that were seen in these participants with posterior falling epiglottis. As can be seen, 12 of the 13 participants with posterior falling epiglottis had normal EGG patterns. Posterior falling epiglottis in these participants was a normal structural deviancy (such a pattern present in quiet breathing as well as phonation tasks) devoid of any functional compensation. These participants were phononormic individuals with no reported voice complaints and/ instances of vocal loading. Hence, though it appeared like MTD III feature (anterior-posterior compression), it was a normal anatomical variance not hampering regular vocal cord vibratory patterns that resulted in normal EGG waveforms also.

In one participant, posterior falling epiglottis was a functional compensation (leading to anterior-posterior compression and a small posterior glottic chink) that was visible only during phonation task. Nevertheless, this participant also was a phononormic individual with no voice complaints and/ frequent vocal loading instances. In this participant, EGG waveform pattern with sight prolongation in the open phase could possibly be due to posterior glottic chink secondary to posterior falling epiglottis (functional compensation).

To conclude, the present study provides vital information regarding EGG waveform patterns that can be suggestive of specific pathological or normal laryngeal conditions. As stroboscopy is not a much feasible procedure in routine clinical practise (owing to the exuberant cost involved and limitation in man power trained to perform stroboscopy), relying on EGG becomes imperative. Thus, the findings of the present study aid the SLPs to make diagnostic inferences more authentically in dysphonic individuals based majorly on EGG data along with other factors such as the case history details, age, gender and other overt vocal symptoms (perceptual quality of voice, throat clearing instances/ presence of cough at the time of testing etc).

4.5. *Extent of association between EGG waveform patterns and stroboscopic findings within each age group in the experimental group*

The participants of the experimental group (517) were divided into five different age groups. These age groups are: 10-18, 18-30, 30-50, 50-65 and 65-80 years. In each age group, the statistical tools, Chi-square test of association and the Cramers-V were applied to examine if there was any association between EGG waveform patterns and stroboscopic findings, and the extent of association present. These tests were not employed for the last age group (65-80 years) as the number of participants in that age group was limited (19/517) and the data values for each EGG pattern were less. Table 4.2, represents the results of Chi-square test and Cramers-V applied to the age groups.

Table 4.2

Chi-square and Cramers V results for the extent of association within each age group

Age groups	*Chi-Square test*	*Cramers-V*
10-18 years	p= 0.001	p= 0.575
18-30 years	p= 0.001	p= 0.564
30-50 years	p= 0.001	p= 0.587
50-65 years	p= 0.001	p= 0.658

As can be seen from Table 4.2, on applying the Chi-square test, there was a statistically significant association between the EGG waveform patterns as well as stroboscopic findings in all the age groups. On executing the Cramers-V test, there was a moderate level of association between the EGG patterns and the stroboscopic findings in all the age groups. As can be seen, in the three age groups of 10-18, 30-50 and 50-65 years, there was a slight increasing trend in the results of Cramers-V test, nevertheless, this increase was not much significant.

Table 4.3

Most frequent EGG waveforms and the associated stroboscopic findings in the first age group (10-18 years)

Most frequent EGG waveform patterns seen	***Most frequently associated stroboscopic findings***
• Normal EGG waveforms	• Normal laryngeal structure and functioning • Early nodular changes
• EGG waveforms with right sided double peak	• Early nodular changes and developed nodules
• Prolonged open phase	• Glottic chink • Sulcus vocalis.

Table 4.3, depicts the most frequent EGG waveforms and the associated conditions in the first age group (10-18 years). As can be seen from Table 4.3, in the first age group (10-18 years), most frequent EGG waveform patterns were: normal EGG wave morphologies, EGG waveforms with right sided double peak and EGG waveforms with prolonged open phase. Normal EGG wave morphologies in this age group were mostly associated with conditions of normal laryngeal structure and functioning and early vocal nodular changes. EGG waveforms with right sided double peak were mostly associated with early nodular changes and developed nodules. This finding is probable as, in this age group children mostly engage in vocal abuse and misuse behaviours leading to development of nodular changes resulting in EGG waveforms with right sided double peaks (Altman, 2007). Prolonged open phase was majorly associated with conditions of glottic chink and sulcus vocalis.

Table 4.4

Most frequent EGG waveforms and the associated stroboscopic findings in the second age group (18-30 years)

Most frequent EGG waveform patterns seen	***Most frequently associated stroboscopic findings***
• Prolonged open phase	• Glottic chink
• EGG waveforms with right sided double peak	• Nodules, polyps, cysts and edematous lesions
• Normal waveform patterns	• Normal laryngeal structure and functioning • MTD

Table 4.4, depicts the most frequent EGG waveforms and the associated conditions in the second age group (18-30 years). In the second age group (18-30 years), most frequent EGG waveform patters were: prolonged open phase, normal EGG waveforms and EGG waveforms with right sided double peaks. Prolonged open phase was mostly associated with conditions of glottic chink. EGG waveforms with right sided double peak were majorly associated with nodules, polyps, cysts and edematous mass lesions. This finding could be mostly due to the fact that majority of the participants in this age group were professional voice users, and mass lesions in these individuals are frequent (Sarfati, 1989; Smolander & Huttunen, 2006). Normal EGG waveforms in this age group were mainly related to conditions of normal laryngeal structure and functioning as well as MTD patterns.

In the third age group (30-50 years), most frequent EGG waveform patters seen were: EGG waveforms with prolonged open phase, right sided double peak in the EGG waveforms and normal EGG waveform patterns. In this age group, the pattern of association between the

EGG waveforms with that of stroboscopic findings exactly mimicked the previous age group (18-30 years) and hence a separate table has not been provided.

Table 4.5

Most frequent EGG waveforms and the associated stroboscopic findings in the fourth age group (50-65 years)

Most frequent EGG waveform patterns seen	***Most frequently associated stroboscopic findings***
• Prolonged open phase	• Glottic chink • Sulcus vocalis
• Aperiodicity in the EGG waveforms	• Carcinomatous lesions on vocal cords • Edematous mass lesions • Vocal cord paralysis
• Impaired cycle-cycle replicablity	• Carcinomatous lesions on vocal cords • Edematous mass lesions • Vocal cord paralysis

Table 4.5, depicts the most frequent EGG waveforms and the associated conditions in the first age group (50-65 years). As can be inferred from Table 4.5, in the fourth age group of 50-65 years, most frequent EGG waveform patters were: EGG waveform with prolonged open time, aperiodicity in the EGG waveforms and impaired cycle-cycle replicablity. Prolonged open time was mostly associated with conditions of glottic chink and sulcus vocalis. Aperiodic waveforms and impaired cycle-cycle replicablity in the EGG wave morphologies were mostly associated with certain edematous and carcinomatous mass lesions; and cases of vocal cord paralysis. It can be noted that, with advancing age, incidences of benign mass lesions decreased and neurological conditions increased.

4.4.1. Assessing the sensitivity and specificity of EGG and videostroboscopy

In order to accomplish the second objective of the study, sensitivity and specificity of EGG and stroboscopy in identifying pathological as well as normal conditions was assessed. Sensitivity and specificity are the terms used to evaluate a clinical test. They are independent of the population of interest subjected to the test. The sensitivity of a clinical test refers to the ability of the test to correctly identify those patients with the disease. Specificity refers to the ability of the test to correctly identify those patients without the disease (Lalkhen & McCluskey, 2008)

In the present study, the sensitivity and specificity of EGG and stroboscopy were calculated separately. In this process, the participants of EGG and stroboscopy were grouped as either “Normal” or “Disordered” and each of their data was analyzed and coded as “Normal =1” or “Identified = 2”.

4.4.2 ***Sensitivity and specificity of EGG***

Sensitivity and specificity of EGG were calculated in the following manner. Normal participants in the control group, identified as normal under EGG wave morphology were termed as “True negative” and those suspected of disorder were termed “False positive”. Disordered participants under the experimental group, identified as normals were termed as “False negative” and those suspected of disorder were termed as “True positive”. Tabulation of these to calculate sensitivity and specificity is provided in Table 4.6.

Table 4.6

Tabulation of sensitivity and specificity details for EGG

Type	**Normal on EGG**	**Identified with some pathology on EGG**	**Total participants**
Normal participants	True Negative (TN) (79)	False Positive (FP) (22)	101
Disordered participants	False Negative (FN) (128)	True Positive (TP) (389)	517
Total	185	433	618

Sensitivity was calculated using the following formula

$$\frac{TP}{TP + FN} = \frac{389}{389 + 128} = 0.75\ (75\%)$$

(* TP: True positive, FN: False negative)

Specificity was calculated using the following formula

$$\frac{TN}{TN + FP} = \frac{79}{79 + 22} = 0.78\ (78\%)$$

(* TN: True negative, FP: False positive)

Using the above mentioned formulae, the sensitivity and specificity of EGG was found to be 0.75 and 0.78 respectively. Sensitivity and specificity values in the range of 0.7-0.9 are considered to be fairly good in terms of the values, and hence the findings from the present study indicate good sensitivity and specificity of EGG. There are a few reports in the literature that address sensitivity and specificity issues of EGG. Similar to the present study, Chunsheng et al. (1998) examined the effects of Electroglottography (EGG) in screening vocal fold disorders and reported that EGG measurement is sensitive to screen vocal fold disorders, and is specific to distinguish benign and malignant diseases.

On the other hand, a few other studies in the literature report good sensitivity and relatively low specificity values of EGG. Wei et al. (2002) reported the sensitivity, specificity and clinical value of EGG measurement in benign vocal fold diseases and concluded that EGG waveform was sensitive to benign vocal fold diseases to a degree, but the specificity was poor. Mayes et al (2008) reported a sensitivity value of 95% and a specificity value of 25% for the EGG waveform.

4.4.3. Sensitivity and specificity of stroboscopy

Sensitivity and specificity of stroboscopy were calculated in the same manner as that of EGG. Normal participants under the control group identified as normal under stroboscopy were termed as "True negative" and those suspected of disorder were termed "False positive". Disordered participants under the experimental group, identified as normals were termed as "False negative" and those suspected of disorder were termed as "True positive". Tabulation of these to calculate sensitivity and specificity of stroboscopy is provided in Table 4.7.

Table 4.7

Tabulation of sensitivity and specificity details for stroboscopy

Type	Normal on stroboscopy	Identified on stroboscopy	Number
Normal participants	True Negative (TN) (101)	False Positive (FP) (0)	101
Disordered participants	False Negative (FN) (56)	True Positive (TP) (461)	517
Total	157	461	618

Sensitivity of stroboscopy was calculated using the following formula

$$\frac{TP}{TP + FN} = \frac{461}{461 + 56} = 0.89\ (89\%)$$

(* TP: True positive, FN: False negative)

Specificity of stroboscopy was calculated using the following formula

$$\frac{TN}{TN + FP} = \frac{101}{101} = 1\ (100\%)$$

(* TN: True negative, FP: False positive)

Using the above mentioned formulae, the sensitivity and specificity of stroboscopy was calculated to be 0.89 and 1.0 respectively. As stroboscopy is a direct glottal visualization technique, it is proved to be successful in providing accurate description and diagnosis of varied voice disorders. High sensitivity and specificity values of stroboscopy obtained in the present study can be augmented by other studies too that reported high values.

In support of the present study, WuGuoYing et al. (2009) reported that the overall sensitivity and specificity of videostroboscopy in diagnosing early vocal cold polyps are much higher than the electro laryngoscope. Uloza et al. (2013) determined the sensitivity and specificity of the basic video laryngostroboscopy (VLS) parameters and concluded that VLS is reliable in clinical settings, demonstrates high sensitivity and specificity distinguishing healthy and pathological voice patients. On the same lines, Demerdash et al. (2015) reported 96.8% sensitivity and 92.8% specificity of stroboscopy with an overall accuracy of 95%.

Literature reveals certain other studies that report high sensitivity and low specificity values of stroboscopy. Wendler et al (2004) reported that videostroboscopy is highly sensitive but barely specific in cases of organic dysphonia and little sensitive and not specific in cases of functional dysphonia. They attributed the finding to the presence of wide variability and inconsistency even in cases of normal vibrations. Similarly, Mehta and Hillman (2012) reported that stroboscopy is sensitive to vocal fold vibratory features; nevertheless, the modality lacks specificity exhibited by High speed video endoscopy that is required for adequate judgments.

To summarize, sensitivity and specificity values of both videostroboscopy and EGG were within acceptable limits. However, the values obtained for videostroboscopy were greater than those that were obtained for EGG. This can be attributed to the fact that stroboscopy is a direct glottal visualization instrument permitting direct viewing of the vocal folds anatomy and functions. EGG is only a non invasive electrophysiological technique allowing inspection of the properties of vocal folds in vibration by measuring electrical resistance/conductance.

CHAPTER V

SUMMARY AND CONCLUSIONS

Instrumental measures of vocal function are an integral and vital component of the clinical process, rather than just a supplement to assessment and treatment. The aim of instrumental evaluation in speech pathology is to provide explanatory accounts of disabilities rather than simple descriptions-however useful these may be as a step towards the definition of a problem (Abberton, Howard and Fourcin 1989). One such edifying objective assessment tool is the Electroglottograph or the Electrolaryngograph.

Electroglottography (EGG) reflects variations in electrical impedance that theoretically result from changes in vocal fold contact area during phonation. EGG is a technique used to examine laryngeal movements, more specifically, the vocal fold movements which provides for an indirect method of observing the degree of contact between tissues in the neck (Titze, 1990). It is entirely noninvasive, impervious to ambient noise, innocuous and yields straight-forward information about the vibratory behavior of the vocal folds during phonation. Owing to the presence of certain pitfalls associated with the instrument, an all-too- naive interpretation of EGG data may prove detrimental, especially in clinical applications. As this tool paves way for an indirect inference of laryngeal vibratory behavior, a more direct glottal visualization system in addition will aid in an auxiliary comprehension of the laryngeal behavior and its functioning. Validity of EGG elucidation necessitates a correlation or an association of the EGG waveform with certain other measurement tools of glottal function. One such comprehensive glottal visualization technique is the *Video-stroboscope.* Laryngeal stroboscopy creates an apparent slow motion view of periodic vocal fold vibrations by effectively sampling successive phases of the movement across successive vocal fold cycles. This is a special instrumental technique that provides a magnified, slow motion view of the vocal cords in action. This technique endows for an accurate diagnosis of conditions and diseases of the vocal folds and certain supra glottal structures including mass lesions, deviancies of vocal cord motion or mobility, inflammatory conditions, arterial or blood supply discrepancies, scarring lesions and other conditions. Nevertheless, there are certain pitfalls associated with the stroboscopic procedure also.

As no single instrumental measure is sufficed in itself for providing accurate, apparent and detailed assessment of the glottis and its functional behavior, phonatory analysis can be triumphant especially when it is validated with other instrumental measures. Hence the objectives of the present study were to estimate a qualitative relationship between EGG patterns and the findings on videostroboscopy and to estimate the accuracy of EGG waveform patterns and stroboscopic findings in recognizing gross anatomical and physiological vocal fold discrepancies.

In the present study, 517 individuals with dysphonia in the age range of 10-80 years were recruited as participants under the experimental group. As an extensive age range was considered, the participants were further divided into five groups (10-18, 18-30, 30-50, 50-65 and 65-80 years). In order to appreciate EGG and stroboscopic characteristics in phononormic individuals, 101 phononormic individuals were considered as participants under the control group.

For the experimental group, detailed case history of the participants was procured following which the EGG (KayPentax model 6103) evaluation was carried out, and the qualitative findings (wave morphology patterns) was documented. Subsequently, videostroboscopy was performed by an Otolaryngologist/Phonosurgeon using Xion Endo-Strobe videostroboscopy system. On examination the parameters reflecting both glottic and supraglottic activity were documented and the overall diagnostic conclusion regarding the vocal mechanism was derived.

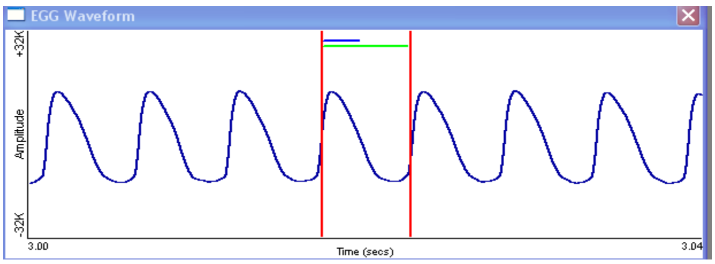
Various EGG waveforms were obtained and based upon the wave morphologies; similar patterns were grouped, classified and numerically coded. On the basis of available literature in this purview and on the clinical experience of the researcher, certain wave morphologies were theorized to signal certain pathological/normal voice conditions. Following this, the participants under experimental group were made to undergo the Videostroboscopic procedure. The *Digital Video Archieve Software (DiVAS)* version 2.5 from *Xion Medical* was used to video record. All the 517 participants' data were classified based on the finer similarity in the stroboscopic diagnosis.

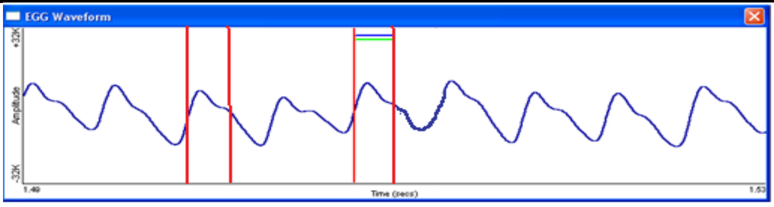
For the control group, a checklist prepared to recruit perceptually phononormic individuals was employed. This checklist was administered on individuals in the age range of 20-60 years and 101 individuals who passed the checklist were selected as participants for the study. Here, all the participants were made to undergo the stroboscopic examination first followed by the EGG procedure. Later, the EGG waveforms were analyzed qualitatively, and the resulting morphologies was grouped and coded on similar lines as done for the experimental group.

In order to accomplish the first objective of the study, the statistical tools, Chi-square test of association and Cramers-V were employed in both experimental and control groups. This was done to examine if there was any association between the findings of EGG and stroboscopy and the extent of association present. In the experimental group, on applying the Chi-square test of association, a statistically significant association ($p = 0.001$) was obtained between the overall EGG wave patterns and the findings on videostroboscopy. On applying the Cramers-V test, a moderate association level ($p = 0.542$) was found between the overall results of EGG and stroboscopy. In the experimental group, on analyzing the EGG waveforms of 517 cases, they could be classified into 13 types of wave morphologies based on the similarity of patterns obtained. Further, on subjecting all these participants to stroboscopic examination, certain laryngeal pathologies were found to be present. Subsequently, each of the EGG waveform patterns was found to be associated with certain laryngeal conditions. Table 5.1, summarizes, each of the EGG waveform types and the associated laryngeal conditions that was obtained in the present study.

Table 5.1

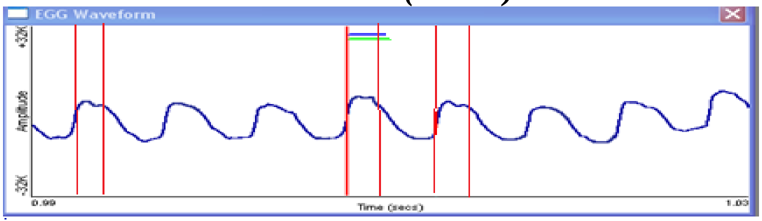
Summary of EGG waveform patterns and the associated stroboscopic findings in the experimental group

EGG waveform pattern	***Associated stroboscopic findings (in percentage)***
1. Normal EGG waveform (127/517) 	• Normal laryngeal structure and functioning: 50/127 (39%) • MTD (19%) • Sulcus vocalis (9%) • Early nodular changes (9%)
2. Right sided notch/double peak in the EGG waveform (91/517)	• Early nodular changes (45%) • Developed nodules (23%) • Polyps (13%)



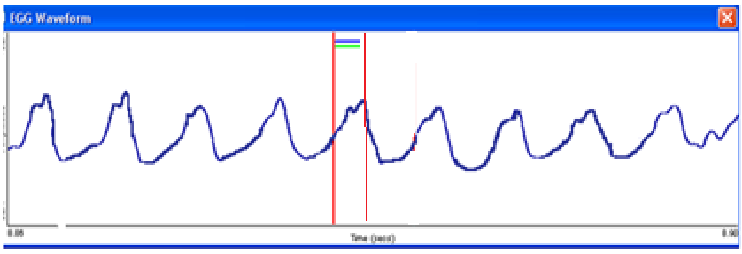
- Edematous lesions (9%)

3. Intermittent double peak in the EGG waveform (32/517)



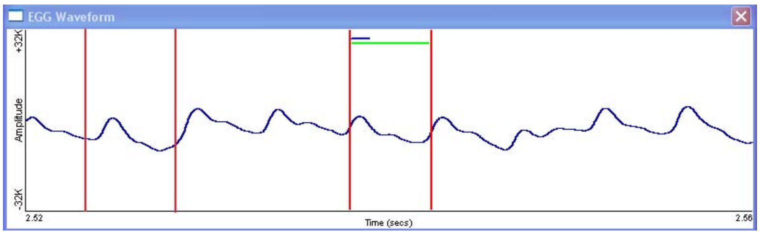
- Polyps (67%)
- Early nodular changes (17%)
- Developed nodules (10%)

4. Left sided notch/double peak in the EGG waveform (26/517)



- Sulcus vocalis (69%)
- Mass lesions (24%)

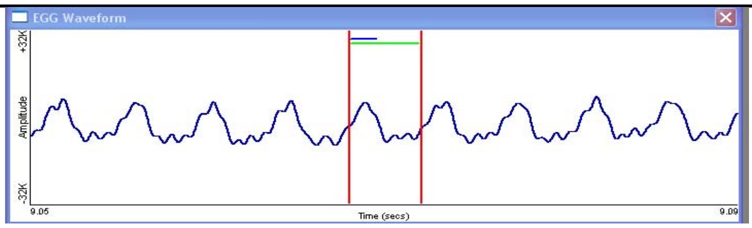
5. EGG waveform with irregular periodicity (21/517)



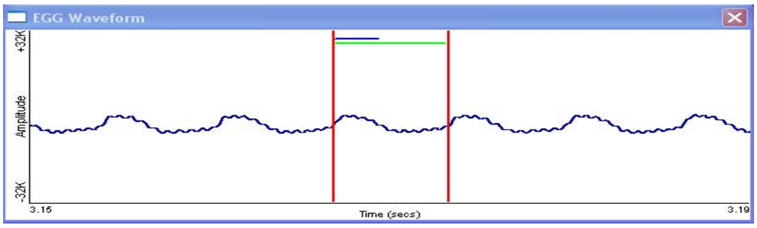
- Unilateral Paralysis (33%)
- Paresis (20%)
- Polyps, cysts and edematous lesions (24%)
- Irregular and spindle shaped glottic chink (19%)

6. EGG waveform with impaired cycle-cycle replicablity (33/517)

- Polyps, cysts, edematous lesions and initial carcinomas (36%)
- Paresis (24%)
- U/L paralysis (21%)

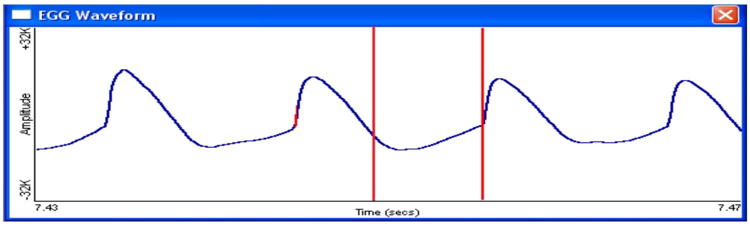


7. EGG waveform with a tremulous pattern (7/517)



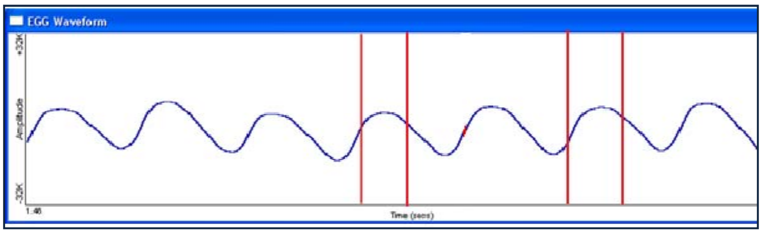
- Neurological tremors (86%)

8. EGG waveform with prolonged open phase (111/517)



- Anterior, spindle shaped and posterior glottic chink (66%)
- Sulcus vocalis (13%)

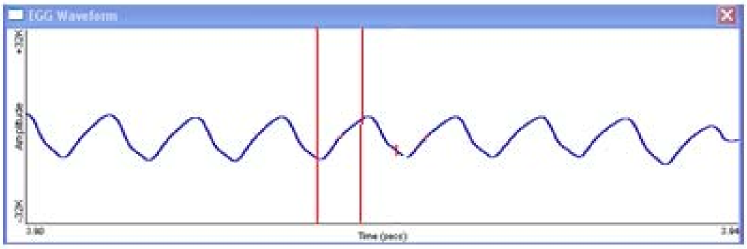
9. EGG waveform with prolonged closed phase (10/517)



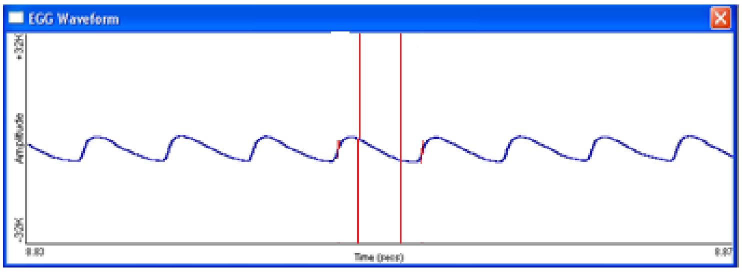
- Glottic chink (80%)
- Spasmodic dysphonia (20%)

10. EGG waveform with prolonged closing phase (21/517)

- Vocal fold paralysis (100%)

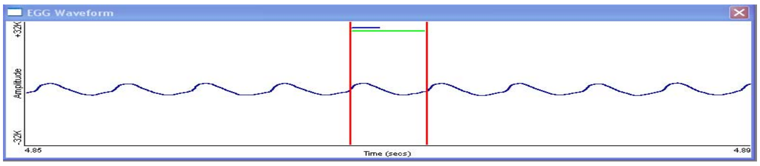


11. EGG waveform with prolonged opening phase (32/517)



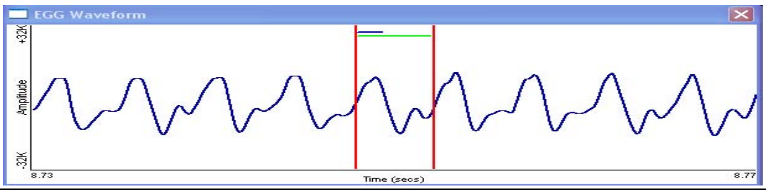
- Glottic chink (60%)
- Mass lesions (18%)
- Sulcus vocalis (13%)

12. EGG waveform with reduced/low amplitude (3/517)



- Sulcus vocalis (67%)
- Mass lesions (33%)

13. EGG waveform with bitonal/biphasic waves (3/517)



- Plica ventricularis (67%)
- Puberphonia (33%)

(* Percentage of the laryngeal associated conditions is derived from the number of participants with a particular waveform exhibiting that particular laryngeal condition. For eg: 39% of participants having normal EGG waveform (127/517) were found to have normal laryngeal structure and function on stroboscopic examination also)

In the control group, on application of Chi-square test and the Cramers-V; statistically significant association ($p = 0.001$) was found between the overall stroboscopic results and

EGG waveform patterns. On applying the Cramers-V, a moderate association level (p = 0.524) was found between the overall results of stroboscopy and EGG. Under the stroboscopic examination three different laryngeal conditions were found in these phononormic participants. They were: normal laryngeal structure and functioning, normal laryngeal structure with small posterior glottic chink; and posterior falling epiglottis. When, these participants were subjected to the EGG procedure, these stroboscopic findings were found to be associated with certain EGG waveform patterns.

In order to accomplish the second objective of the study ie, assessing the accuracy of EGG and stroboscopy, sensitivity and specificity of each was tested. The sensitivity and specificity of EGG and stroboscopy was found to be 0.75 and 0.78 and 0.89 and 1.0 respectively. Sensitivity and specificity values in the range of 0.7-0.9 are considered to be fairly good, and hence the findings from the present study indicate good sensitivity and specificity of EGG and stroboscopy.

As the entire age range was subdivided into five different age groups, extent of association in each age group was also examined by the statistical tools of Chi-square test and the Cramers-V. On applying these tests, moderate level of association between the EGG waveform patterns and the stroboscopic findings was obtained in all the four age groups (10-18, 18-30, 30-50 and 50-65 years). Only in the last age group (65-80 years), these tests were not carried out, as the number of participants in this age group was very limited (19/517).

To conclude, the present study provides vital information regarding EGG waveform patterns that can be suggestive of specific pathological laryngeal conditions. This will aid the SLPs to make a diagnostic inference more authentically in dysphonic individuals based majorly on EGG data along with other factors such as the case history details, age, gender and other overt vocal symptoms (perceptual quality of voice, throat clearing instances/ presence of cough at the time of testing etc).

5.1. Implications of the study

1. As EGG is the most viable and frequently utilized instrument by a huge corpus of SLPs in India, the present study would greatly contribute to enhance its reliability factor in clinical practice.
2. The findings of the study may pave way for EGG results to be relied and incorporated with a stronger and a more authentication interpretation both with and without the facility for stroboscopic evaluation.
3. Correlation or association analysis of the vibratory patterns of vocal folds obtained via EGG and videostroboscopy aid in providing a more comprehensive insight into the pathophysiology of disordered phonation and advocates the evident role of underlying complex mechanisms of vocal outcome.
4. The present study would be extremely instrumental in enhancing the services provided to voice disordered clients as it permits a comprehensive discussion with other voice care professionals specially the Laryngologists and aids in outlining the line of intervention too.
5. The current study assists in a firm outlook regarding the prognosis of voice disordered client undergoing therapy based upon the more legitimate visual feedback of EGG when performed at various stages during therapy.
6. With stroboscopic examination, other subtle lesions, like the nonvibrating segments of vocal folds too can be visualized. These finer findings are often obscured by the more obvious lesions without visualization or stroboscopic documentation. Such findings aid in

the clear-cut decision making regarding the need for and outcomes of laryngeal microsurgeries.

5.2. Limitations of the study

1. The EGG signal is more vulnerable to the placement of electrodes, the distance between the electrodes, and to the artefacts induced into the signal by head movements or vertical shifts of the larynx. These confounding variables at times might have imposed a threat to the reliability of and accuracy of EGG data thus obtained in turn leading to a false positive/ false negative interpretation of the signal.
2. Quantitative EGG data in terms of the EGG quotients was not considered. This if considered would have been more valuable for the validation of EGG findings with that of videostroboscopy.
3. Stroboscopic recordings could not be carried out immediately after the EGG procedure in a few participants. During this time lapse, it is possible that the participants might have indulged in some form of vocal loading tasks or vocal abusive/missusive behaviours. This could have resulted in development of MTD like features and/ laryngeal inflammations on stroboscopic examination, thus misleading the accurate validation process.
4. Gender and occupation equalization could not be carried out in the present study which would otherwise highlight whether better comparisons or associations could be obtained in males or females and professional voice users or non professional voice users.

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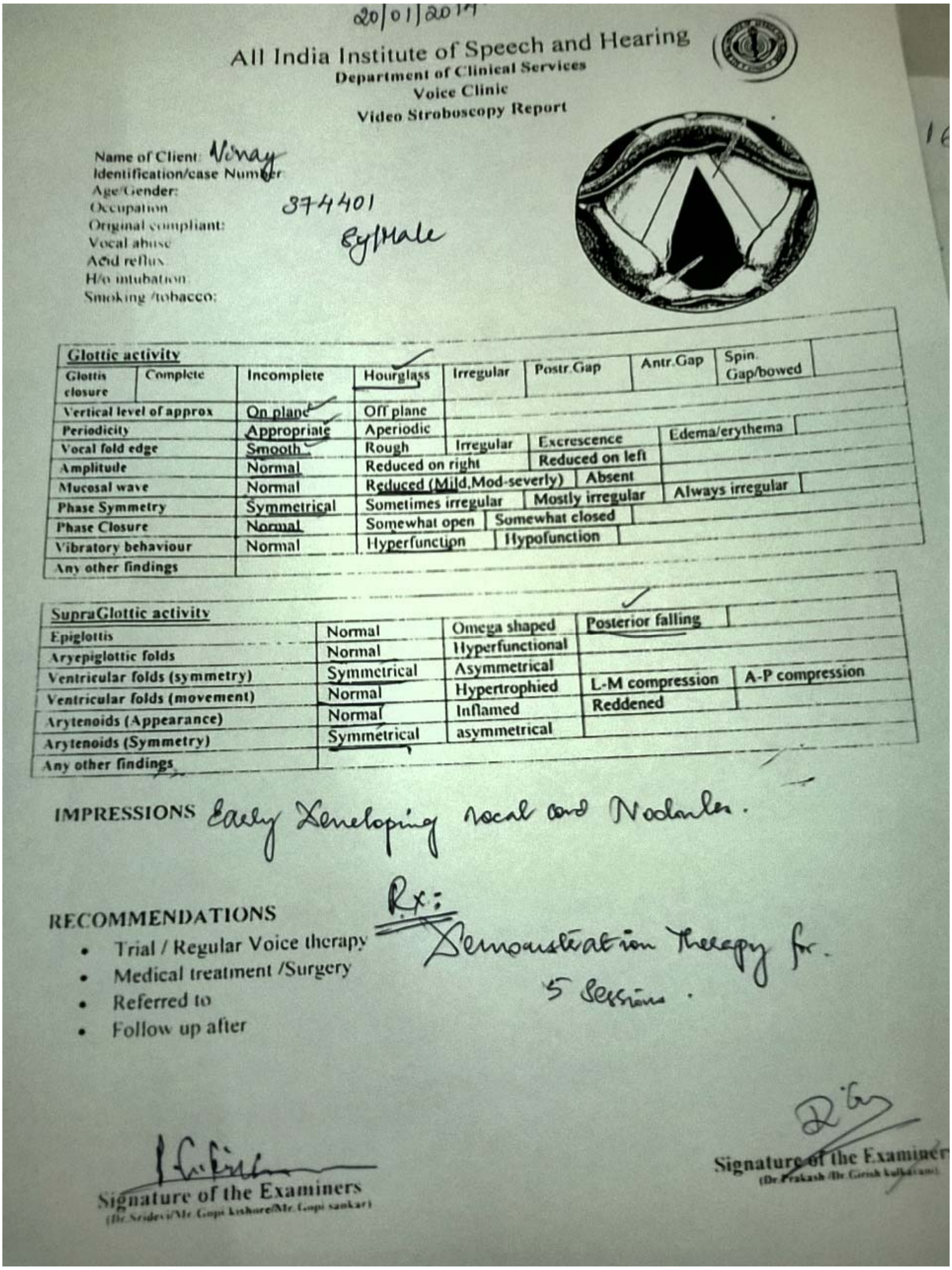
APPENDIX 1

CHECKLIST FOR RECRUITMENT OF NORMAL SUBJECTS

1. No complaints of any form of voice problems (voice change, vocal strain, dryness of throat, throat pain, itching sensation in throat etc) at the time of testing.	**Yes**	**No**
2. Having a perceptually normal voice in accordance to their age and gender.	**Yes**	**No**
3. Devoid of any form of upper respiratory infections at least 2 weeks prior to the day of testing.	**Yes**	**No**
4. Devoid of vocal overloading for more than 2-3 hours/ day.	**Yes**	**No**
5. Devoid of any form of vocal abuse or misuse at least 3 days prior to the day of testing.	**Yes**	**No**
6. Devoid of vocally harmful habits such as excess throat clearing, grunting, speaking at extreme falsetto or vocal fry etc.	**Yes**	**No**
7. Absence of systemic conditions that might influence voice such as Diabetes Mellitus or any neuromotor disorders.	**Yes**	**No**
8. Absence of nasal blockage, nasal discharge or any gross septal deviations as observed on anterior Rhinoscopy.	**Yes**	**No**

APPENDIX II

An illustration of the stroboscopic report form that was incorporated in the present study



20/01/2014

All India Institute of Speech and Hearing

Department of Clinical Services

Voice Clinic

Video Stroboscopy Report

Name of Client: Vinay
Identification/case Number: 374401
Age/Gender: 8y/Male
Occupation
Original compliant:
Vocal abuse
Acid reflux
H/o intubation
Smoking /tobacco:

Glottic activity							
Glottis closure	Complete	Incomplete	Hourglass	Irregular	Postr.Gap	Antr.Gap	Spin. Gap/bowed
Vertical level of approx		On plane	Off plane				
Periodicity		Appropriate	Aperiodic				
Vocal fold edge		Smooth	Rough	Irregular	Excrescence	Edema/erythema	
Amplitude		Normal	Reduced on right		Reduced on left		
Mucosal wave		Normal	Reduced (Mild,Mod-severly)		Absent		
Phase Symmetry		Symmetrical	Sometimes irregular		Mostly irregular	Always irregular	
Phase Closure		Normal	Somewhat open		Somewhat closed		
Vibratory behaviour		Normal	Hyperfunction		Hypofunction		
Any other findings							

SupraGlottic activity				
Epiglottis	Normal	Omega shaped	Posterior falling	
Aryepiglottic folds	Normal	Hyperfunctional		
Ventricular folds (symmetry)	Symmetrical	Asymmetrical		
Ventricular folds (movement)	Normal	Hypertrophied	L-M compression	A-P compression
Arytenoids (Appearance)	Normal	Inflamed	Reddened	
Arytenoids (Symmetry)	Symmetrical	asymmetrical		
Any other findings				

IMPRESSIONS Early Developing vocal cord Nodules.

RECOMMENDATIONS

- Trial / Regular Voice therapy
- Medical treatment /Surgery
- Referred to
- Follow up after

Rx: Demonstration Therapy for. 5 Sessions.

Signature of the Examiners
(Dr.Sridevi/Mr.Gopi kishore/Mr.Gopi sankar)

Signature of the Examiner
(Dr.Prakash /Dr.Girish kulkarni)

APPENDIX III

Stroboscopic report form developed by the Voice clinic, AIISH (2013)

Parameter (Glottal activity)						
Glottis closure	Complete (Normal)	Irregular/ Incomplete	Hourglass	Posterior glottis chink	Anterior Gap	Spin/ Bowed
Vertical level of approx	On plane	Off plane				
Periodicity	Appropriate	Aperiodic				
Vocal fold edge	Smooth	Rough	Irregular	Excrescence	Edema/ Erythema	
Amplitude	Normal	Reduced on right	Reduced on left			
Mucosal wave	Normal	Reduced (Mild, Mod-Severely)	Absent			
Phase symmetry	Symmetric	Sometimes irregular	Mostly irregular	Always irregular		
Phase closure	Normal	Somewhat open	Somewhat closed			
Vibratory behaviour	Normal	Hyperfunction	Hypofunction			
Parameter (Supraglottal activity)						
Epiglottis	Normal	Omega shaped	Posterior falling			
Aryepiglottic folds	Normal	Hyperfunctional				
Ventricular folds	Symmetric	Asymmetrical				
Ventricular folds (movement)	Normal	Hypertrophy	L-M Compression	A-P compression		
Arytenoids appearance	Normal	Inflamed	Reddened			
Arytenoids symmetry	Symmetric	Asymmetrical				