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Assessment of vocal fold Phonatory function A Review

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Abstract:

This article attempts to review the various imaging modalities that can be used to assess vocal fold function including development of indirect laryngoscopy, direct laryngoscopy, video laryngoscopy, stroboscopy etc. Focus of this article is primarily on imaging approaches for observing / documenting vibratory behaviour of vocal folds during phonation.

Introduction:

Past 150 years has seen nearly 4 major technological developments that have contributed to the current understanding of vocal fold Phonatory function.

1. Indirect laryngoscopy
2. Imaging of rapid motion
3. Fibre optics
4. Digital image capture

Indirect laryngoscopy:

This involves use of reflected light and images to observe functioning larynx. It was Phillip Bozzini [1] in 1807 who designed an instrument that facilitated looking into natural orifices of the human body (throat, rectum).

This instrument was named the "Lichtleiter" i.e. light conductor. It used a candle and a reflector to direct light through probes / tubes of various sizes. The cannula he designed for examination of throat had an additional mirror which facilitated evaluation of lower pharynx and larynx.

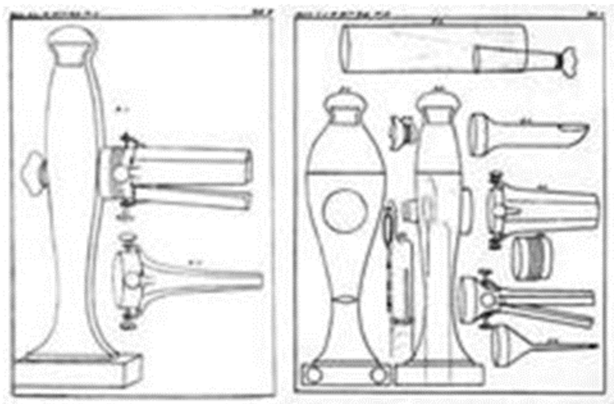


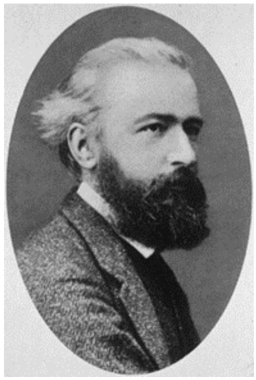
Diagram of Lichtleiter [2]

Many other similar devices were described during the same period, but none of them attracted the attention as Lichtleiter. It was the Italian singer Manual Garcia [3] who popularized auto laryngoscopy (self-performed mirror laryngoscopy).

Garcia accidentally viewed his vocal folds when he was having a hair cut in a barber's mirror. He conducted a series of experiments before publishing his work titled "Observations on the Human voice "at the Royal society of London in 1855. This facilitated physicians like Clerf, Turck, and Czermak to adopt mirror laryngoscopy to visualize the vocal folds.

Ludwig Turck [4]

In 1857 Ludwig Turck Professor of laryngology Vienna (Austria) learning about Garcia and his success travelled to Paris to observe first-hand the work of Garcia. Turck adapted Garcia's technique and designed an indirect laryngoscope. He used natural sunlight for illumination. He used a larger mirror than Garcia to reflect sunlight into the throat.



Johann Nepomuk Czermak [5]

Shortly after Turck Johann Nepomuk Czermak Professor of physiology from Czechoslovakia modified Turck's laryngoscope by using independent light source from a pump lamp with a double wick. He also used a concave mirror to concentrate light. These two innovations made his instrument more effective and dependable. He also became the founder of laryngoscopy from then on. .One more milestone achieved by Czermak is that he was the first person to take a photograph endoscopically of human larynx. This really marked the first turning point in the field of laryngology

Next turning point in laryngoscopy occurred in 1867 with the use of the glow produced by galvanised platinum wire to illuminate body cavities. Galvanised platinum produced heat while generating the glow. Julius Burk in 1866 designed a glass cooling encasing which reduced the amount of heat generated. Light sources began to be placed inside the body cavity rather than outside. This brought about a new revolution in endoscopy.

Fibre optics:

In 1950 Hopkin's and his colleagues experimented with glass fibers and attempted to transmit light and images through it. His team was responsible for the development of rod lens system which is the basic technology for the currently available video laryngoscopes.

Visualization of rapidly moving vocal folds:

During acts of phonation vocal folds are known to open and close at least 100 times a second. Their velocities of vibrations could easily reach 1 meter / second which is way above the resolving capacity of human eyes. Dynamic motions of the vocal folds cannot be discerned by naked eyes. Stroboscopy has a vital role to play in this aspect. Stroboscopy is actually based on creating optical illusion in which rapid motion of the vocal folds appear to be slowed down to a perceivable rate by illuminating with light that flashes at an appropriate frequency. Earlier literature have attributed this effect to Talbot's law of persistence of vision. Actually this effect according to Mehta, Deliyski, & Hillman, 2010 [6] is due to perception of flicker free light intensity and the perception of apparent motion from sampled images.

The first stroboscope was designed by Oertel a German physician in 1878. In this laryngostroboscope he used rotating pinwheel in front of the light source to produce flashes of light needed for viewing the vibrating vocal fold. The major challenge faced by the surgeon is to sync the fundamental frequency of the vocal fold with that of the speed of pin wheel rotation in order to achieve a stable image. This problem was solved in 1950 [7] when systems were developed that could synchronize automatically the fundamental frequency of the vibrating vocal fold and the speed of the flashed light.

Max Joseph Oertel

Stroboscopy:

Laryngeal stroboscopy has evolved now to become a gold standard among voice assessment tools. It has its own disadvantages too:

1. To visualize strobe effect the motion observed should be reasonably periodic. Hence it is incapable of revealing vocal fold vibratory patterns once dysphonia (aperiodicity) sets in.
2. It provides only a global visualization of periodic motion and is not sensitive enough to capture cycle to cycle variations in vocal fold movements [8]. This can be overcome by high speed imaging because recordings are performed at rates higher than that of the vocal fold's fundamental frequency.

Digital Image capture:

Image capturing devices were in vogue since 1930's. Initially this technology was used for military purposes, later their use in television and Medicine followed. CCD (charged coupled devices) developed by Bell laboratories had a huge role to play in this technology.

Digital image capture is the technology that converts electrical signals from image capturing devices into zero's and one's which could be understood by a computer. The brightness of several parts of an Image are encoded and stored in a binary format within a specified dynamic range.

High definition video stroboscopy:

This technology offers unparalleled image resolution of vibrating vocal folds. Images recorded using high definition video cameras have high pixilation with magnification.

The following parameters are evaluated using video stroboscopy:

1. Amplitude – Extent of lateral displacement of vocal folds
2. Mucosal wave – Extent of vocal fold tissue deformation
3. Vibratory behaviour – Presence / absence of vibrations in particular locations of vocal cords
4. Supraglottic activity – Extent of laryngeal compression
5. Edge – Ratings of smoothness and straightness of the edges of vocal folds
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 – Describes the shape of glottic closure

Videostrobokymography:

Videostrobokymography is a technique used to visualize the vibratory pattern of mucosal edges of vocal folds at selected coronal sections along the longitudinal glottic axis [9]. This was originally introduced in 1970's as an analytical tool for examination of periodic and aperiodic vibration of vocal folds.

Uses:

1. It is used in quantitative documentation of abnormal vocal fold vibrations in various benign lesions like vocal nodules, polyps, Reinke's oedema and unilateral vocal fold palsy.

2. Analysis of glottal onset and offset

3. Evaluation of the micro dynamic features of the individual oscillatory cycles of the vocal folds

4. Studying vocal tremor

5. Imaging the mechanism of coughing

6. Evaluation of the velocity of the abductory and adductory movement of the vocal folds

Procedure:

A single coronal selection / slice of vocal fold vibration is recorded during stroboscopy and is analysed over a specified time scale to produce a 2 dimensional image of vibrating vocal fold. Typical vocal fold vibration produces a typical rhomboid kymographic pattern. Any aberration from this pattern is considered abnormal.

This procedure digitalizes the recorded stroboscopic images and analyses them using proprietary software. Major advantage of this procedure is that repeated laryngoscopic examinations are not needed, and computer software is used to analyse the images in different positions of interest.

Image showing video kymograph

Factors that must be considered before evaluation of kymograph images:

1. Position along glottic axis
2. Type of voice produced

In normal cases middle portion of the vocal fold is considered to be representative for the vibration pattern of the entire vocal cord. In vocal fold lesions the vibratory patterns differ along glottal axis.

Type of voice produced:

There are at least three main characteristics of voice which one should take into consideration before interpreting these images:

Phonation pitch

Phonation loudness

Phonation type / voice register

Depth kymography:

Traditional laryngoscopic images are two dimensional and along the horizontal plane, whereas depth kymography laser is used to triangulate and track vertical movements of vocal folds during phonation [10]. This superior – inferior dimension is missing in conventional laryngoscopic images.

Conclusion:

Video stroboscopic examination of larynx is currently common. It not only helps in the diagnosis of voice related pathologies, but also helps in ascertaining the chances of these patients regaining their original voice following surgical therapy. Patients can be informed prior to surgery whether they have any chance of regaining normal voice after surgery by looking for the presence or absence of mucosal waves in stroboscopic examination. If mucosal waves are present in the disease free areas of vocal folds, then there is a bright chance that the patient may regain normal voice after removal of mucosal lesion by microlaryngeal surgery.

Currently emerging technologies like laryngeal high speed video endoscopy offer exciting prospects in functional examination of larynx.

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