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A Review of Changes Induced by Tobacco Smoking and Smoking Cessation on Vocal Health

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Abstract: Smoking tobacco affects vocal health by causing changes in the respiratory and laryngeal systems. Several studies have been conducted to investigate the histopathological, physiological and functional effects of smoking on voice. The current review aimed to examine studies that explored the effect of smoking on both respiration and phonation. The findings show differences in the experimental models used criteria for subject selection, follow-up of subjects over time and control for other factors that affect the human's voice besides smoking. Additionally, findings of multiple studies performed to analyze the same set of parameters demonstrated contradicting results. Most studies examine the smokers voice while research on effect of smoking cessation on voice was not given enough attention. The limitations of the previous research in this area implies that more extensive research is still needed where these variables are controlled and all factors affecting the results of the study are accounted for. It must be noted that investigations of smoking effect and the effect of smoking cessation are in need to fully understand the problem and find ways to help smokers regain normal voice that will improve their quality of life.

Key words: Vocal health, tobacco, smoking, smoking cessation, respiration, phonation

INTRODUCTION

Tobacco use has a major negative effect on human health and contributes to change in the quality of life of a smoker due to tobacco consumption (Owing, 2005). Epidemiological research investigating use of tobacco, focused primarily on tobacco smoking giving it more importance compared to any other form of tobacco consumption (Hamdan *et al*., 2010).

Tobacco use is often linked to heart attacks, strokes, Chronic Obstructive Pulmonary Disease (COPD), emphysema and cancer (particularly lung cancer and cancers of the larynx and mouth) (Owing, 2005). It also causes peripheral vascular disease and hypertension (OSG., 2004). The impact of smoking depends on the length of time that a person smokes and on the amount of consumption. Starting smoking earlier in life and smoking cigarettes that are non-filtered and higher in tar content, increases the risk of these diseases (Frederiksen and Martin, 1979).

There are over 62 known chemical carcinogens in cigarette smoke (Hecht, 1999). Tobacco contains nicotine which is a highly addictive psychoactive chemical (Pryor, 1997). In 1998, the National Institute of Health, through the National Cancer Institute, determined that tobacco smoking causes a variety of cancers including cancers of the oral cavity (lip, tongue, mouth, throat), esophagus, larynx and lung. Tobacco smoke includes several other damaging compounds (Hecht, 1999). Tar is one of the most destructive substances in tobacco smoke. It contains the carcinogen called benzo [a] pyrene that is known to trigger tumor development. Carbon monoxide is another compound that is an odorless gas and is fatal in large doses because it takes the place of oxygen in the blood by binding to hemoglobin. Hydrogen cyanide stops lung clearance system from working properly by affecting the cilia which leads to build up of the poisonous chemicals in tobacco smoke inside the lungs (Hecht, 1999). There are the other chemicals that contribute to damaging the lungs. These chemicals include hydrocarbons, nitrous oxides, organic acids, phenols and oxidizing agents. Tobacco smoke also contains free radicals (Pryor, 1997; Hecht, 1999), metals (Hecht, 1999; Rodgman and Perfetti, 2008) and radioactive compounds that are known to be carcinogenic (Hecht, 1999).

The respiratory system is not the only structure that is affected by tobacco consumption. It can cause long-term damage to the larynx and vocal folds as well. According to the National Institute on Deafness and

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Other Communication Disorders (NIDCD), smoking is considered a phonotraumatic behavior that contribute to laryngeal injury, inflammation and physiological change of the laryngeal system (Sapienza and Ruddy, 2009). Frequent damage induced by smoking, changes the way the laryngeal system works and affects the smoker's voice. Moreover, it can lead to more severe consequences such as cancer that can develop at any level of the larynx (Prout *et al*., 1997).

This study sheds the light on the literature that has been published on the impact of smoking and tobacco consumption on vocal health, focusing on the adverse feffects on the respiratory and laryngeal systems and how smoking contributes to histopathological and physiological changes of these systems. Moreover, attempts to measure the effect of smoking objectively are discussed and the limitations of past research that can gear trends of the future research endeavors are highlighted.

MATERIALS AND METHODS

Effect of smoking on the respiratory system: Constituents of tobacco smoke cause damage to the whole respiratory system including both the main and peripheral airways (bronchi and bronchioles) as well as damage to the alveoli (air sacs) (Aubry *et al*., 2000). This results in changes in the physiological function of the lungs (Gold *et al*., 1996) as well as its function as the driving force that sets the vocal folds into vibration during phonation (Stemple *et al*., 2000). Hence, it is imperative to study the effect of smoking on the respiratory system when the laryngeal system is under investigation.

Histopathological changes of the respiratory tract: Smoking has multiple damaging effects to the respiratory tract such as lung and throat cancer, lung diseases such as chronic obstructive pulmonary disease which includes chronic bronchitis and emphysema, damage to the trachea and lung function and long term effects that include but not limited to narrowing of the lung airways and increased risk of lung infection (Dye and Adler, 1994; Smolley and Bruce, 1998). Some changes are sudden and last a short time. These changes are acute such as colds and pneumonia (Shintani *et al*., 2000). Other changes happen slowly and last for a long time. These are chronic changes and may last for the rest of an individual's life (Aubry *et al*., 2000). Emphysema is an example of a chronic change due to tobacco smoke exposure (Dye and Adler, 1994; Aubry *et al*., 2000; Hendrick, 2004; Lowell *et al*., 1956).

The lungs and airways get irritated and inflamed by smoking. They become narrow and reduce the air flow (Leeder, 1975). In addition, toxic substances are released from tobacco smoke which enters the air sacs of the lungs. The walls of the air sacs are thin and fragile (Wright *et al*., 1992; Aubry *et al*., 2000), therefore, these toxic substances damage the walls of the alveoli (Aubry *et al*., 2000). Damage to the air sacs is irreversible (Leeder, 1975) and results in permanent holes in the tissues of the lower lungs (Aubry *et al*., 2000). As air sacs are destroyed, the lungs transfer less and less oxygen to the bloodstream, causing shortness of breath (Fessler *et al*., 2003). Air does not fill in the air sacs because they cannot shrink completely which impairs ventilation (Voekel and MacNee, 2002). So, the lungs lose elasticity (Xu *et al*., 1992) and they become unable to fully expand and contract (Voekel and MacNee, 2002) which leads to difficulty in exhaling (Moore, 1971). Although, the damage cannot be cured giving up smoking helps to slow down the rate of loss of lung capacity (Hojslet *et al*., 1990). Nonetheless, this reduced ability of the lung to move air in and out results in a reduction of airflow and subglottal air pressure that is responsible for vibrating the vocal folds for phonation. Consequently, it affects the quality of voice, since, it leads to decreased loudness, decreased maximum phonation time (Hillel *et al*., 1989; Vaca *et al*., 2015) and a breathy vocal quality (Leino *et al*., 2008).

Physiological changes of the respiratory system: Pulmonary function testing aims to assessing the functional status of the lungs. This type of tests relates to the volume of air that is moved in and out of the lungs, the airflow rate, lung compliance and the diffusion characteristics of the membrane through which the gas moves (Cherniack, 1992; Crapo, 1994). The primary instrument used in pulmonary function testing is the spirometer. It is designed to measure changes in volume and flow (Cherniack, 1992). Normal values are based upon a person's age, height, ethnicity and sex and are expressed as a percentage (Levitzky, 2018).

Tobacco smoking and lung function has been studied extensively over the last decade. Lung function in relation to smoking was investigated on more than one aspect. The classification of smokers within these studies was based on the cigarette consumption and subjects were usually grouped or categorized as none-smokers, current and ex-smokers (Barter and Campbell, 1976; Tinker *et al*., 1976; Xu *et al*., 1994; Gold *et al*., 1996; Scanlon *et al*., 2000; Chinn *et al*., 2005) and sometimes never-smoker (Higgins *et al*., 1993; Xu *et al*., 1994; Gold *et al*., 1996). A finer distinction was made by looking

at different levels of smoking status such as the intensity of smoking (light vs. heavy) current smoker (Xu *et al*., 1994; James *et al*., 2005) and cessation consistency of quitting smoking (sustained, intermittent or restarter) (Comstock *et al*., 2008; Leeder, 1975; Bosse *et al*., 1981; Camilli *et al*., 1987; Xu *et al*., 1994; Sherrill *et al*., 1996; Scanlon *et al*., 2000; Pelkonen *et al*., 2001; Tashkin *et al*., 2001; Anthonisen *et al*., 2005). Other studies looked at the effect of smoking on respiration in specific populations such as individuals with Chronic Obstructive Pulmonary Disease (COPD) (Scanlon *et al*., 2000) or Asthma (Krzyzanowski *et al*., 1990; James *et al*., 2005). The studies were also different in the way they follow up the study subjects. A few of them followed the participants on a yearly basis (Gold *et al*., 1996; Scanlon *et al*., 2000) while others examined them twice with a duration between 5 and 9 years apart (Comstock *et al*., 2008; Barter and Campbell, 1976; Chinn *et al*., 2005).

Forced Expiratory Volume in 1 sec (FEV_1) (Comstock *et al*., 2008; Leeder, 1975; Barter and Campbell, 1976; Tinker *et al*., 1976; Bosse *et al*., 1981; Taylor *et al*., 1985; Camilli *et al*., 1987; Lange *et al*., 1989; Krzyzanowski *et al*., 1990; Townsend *et al*., 1991; Xu *et al*., 1992, 1994; Sherrill *et al*., 1996; Scanlon *et al*., 2000; Vollmer *et al*., 2000; Pelkonen *et al*., 2001; Tashkin *et al*., 2001; Anthonisen *et al*., 2005; Chinn *et al*., 2005, James *et al*., 2005; Moshammer *et al*., 2006) Forced Vital Capacity (FVC) (Higgins *et al*., 1993; Gold *et al*., 1996; Vollmer *et al*., 2000; Moshammer *et al*., 2006) the ratio of (FEV_1/FVC) and Forced Expiratory Flow (FEF) measures were described in many studies as the earliest spirometric indicators of airway obstruction and small airway disease in adult smokers (Gold *et al*., 1996).

The general trend found in smoking men and women is that the prevalence rates of abnormally low FEV_1 and FVC levels were lowest in never smokers, intermediate in former smokers and highest in current smokers (Higgins *et al*., 1993; Chinn *et al*., 2005; Moshammer *et al*., 2006). The negative association of smoking status with FEV_1 level increased with increasing number of cigarettes smoked (Lange *et al*., 1989). FEV_1 levels was highest in nonsmokers, lower in ex-smokers and even lower in current light smokers and lowest in current heavy smokers (Bosse *et al*., 1981; Higgins *et al*., 1993; Sherrill *et al*., 1996; Scanlon *et al*., 2000; Chinn *et al*., 2005; Moshammer *et al*., 2006). Among sustained quitters, lung function improved more in the first year for formerly heavy smokers than for light smokers (Scanlon *et al*., 2000). Compared with those who had never smoked, decline in FEV1 was lower in male sustained quitters than female sustained quitters (Chinn *et al*., 2005). Analysis adjusted for height, age and smoking variables, it was found that females are more susceptible to cigarette smoking than males (Xu *et al*., 1994).

Lung function in relation to tobacco smoking was investigated in several large cross-sectional and longitudinal studies. Tobacco smoking has a strong dose-dependent association between tobacco smoking and reduced FEV_1, FVC and FEV_1/FVC in both sexes (James *et al*., 2005). This result confirms the conclusions from a regression analysis of eight large US population-based studies (Vollmer *et al*., 2000) and a longitudinal study from Netherlands (Pelt *et al*., 1994). However, other cross-sectional studies such as a respiratory health study by Xu *et al*. (1994) conducted in Beijing, a Canadian study by Chen *et al*. (1991), the Tucson study by Burrows *et al*. (1986) and both a cross-sectional and longitudinal study from Copenhagen (Lange *et al*., 1989; Prescott *et al*., 1998) have reported a greater decline in lung function among females than males, associated with tobacco smoking. On the other hand, opposite results have been found in both cross-sectional and longitudinal studies such as the six cities study (Xu *et al*., 1992) a study by Camilli *et al*. (1987) a study in the Netherlands by Pelt *et al*. (1994) and the UCLA study from Los Angeles (Tashkin *et al*., 2001).

Although, there were no studies that particularly investigated the relationship between respiratory ability of smokers and their voice quality, it is evident that normal voice requires normal breathing (Dromey and Ramig, 1998; Hixon and Hoit, 2005). There is a direct relationship between normal voice and the vital capacity of the lungs (Dromey and Ramig, 1998; Hlastala and Berger, 2001). Spirometric parameters used to measure lung function such as FEV_1, FVC and FEV_1/FVC is associated with voice quality (Hillel *et al*., 1989; Leino *et al*., 2008; Vaca *et al*., 2015). Hence, one can safely conclude that the effect of smoking on a human's voice is two-fold an indirect effect on respiration as the driving force to set the vocal folds into vibration for phonation and the direct effect on the structure and function of the voice box itself.

Effect of smoking on the laryngeal system:

Histological changes of the vocal folds: The histological structure of the vocal fold can be divided into 5 tissues that can be categorized into three sections. The cover, the transition and the body. The cover is composed of the epithelium (mucosa), basal lamina and the superficial layer of the lamina propria. The transition is comprised of the intermediate and deep layers of the lamina propria. And the body is composed of the thyroarytenoid muscle

(Sapienza and Ruddy, 2009). This layered structure of tissues is very important for vibration of the true vocal folds (Titze and Scherer, 1983). On the surfaces of the epithelial cells are microridges and microvilli (Stemple *et al*., 2000). The basal lamina is transitional tissue composed of two zones, the lamina lucida and lamina densa. The superficial layer of the lamina propria consists of loose fibrous components and extracellular matrices that is similar to soft gelatin (Moharamzadeh *et al*., 2007). This layer is also known as Reinke's space (Sapienza and Ruddy, 2009). This layer vibrates a lot during phonation (Titze and Scherer, 1983). The elasticity needed to support this vibratory function depends mostly on extracellular matrices (Hay, 1991). The primary extracellular composition of the vocal fold cover is fibers that are reticular, collagenous and elastic as well as glycoprotein and glycosaminoglycan. These fibers give structural maintenance by providing strength and flexibility, so that, the vocal folds may vibrate freely but still keep their shape (Moharamzadeh *et al*., 2007). The intermediate layer of the lamina propria is primarily composed of elastic fibers while the deep layer of the lamina propria is primarily composed of collagenous fibers. These fibers are parallel to the vocal fold edge and these two layers of the lamina propria comprise the vocal ligament (Sapienza and Ruddy, 2009). The transition layer is primarily structural, giving the vocal fold support as well as providing adhesion between the cover, the body and the thyroarytenoid muscle (Moharamzadeh *et al*., 2007). The thyroarytenoid muscle is divided into the thyrovocalis and the thyromuscularis (Moore, 1971; Sapienza and Ruddy, 2009).

Lots of attempts have been made to understand the mechanism of damage caused by tobacco smoking in humans. The larynx was considered the organ most sensitive to histopathological changes after exposure to cigarette smoke (Haussmann *et al*., 1998). Studies investigating this subject varied in terms of the experimental model used and other variables such as concentration and duration of exposure. Since, it is difficult to study the histological composition of a smoker's larynx, researchers used animal experimental models and cadaver models. The rat larynx has been extensively used as an experimental model for speech, since, its shape is similar to the human larynx which allows some comparisons of its vocal behaviors (Isik *et al*., 2004; Duarte *et al*., 2006). Most studies observed the pathological reactions stimulated by inhalation of cigarette smoke in rats. Regardless of the differences in the brand of tobacco used, the exposure system to smoke and the temperature in the exposure chambers. Studies investigating the effect of smoke on the histology of the larynx show similar results. Isik *et al*. (2004) reported high levels of plasma thiocyanate concentration after smoke exposure which was referred to as a good indicator of smoke exposure. Moreover, they reported disturbed stratification of the true vocal folds with loss of the desmosomal connection among epithelial cells and enlargement of intercellular spaces. Deterioration and irregularity of the luminal surface of the superficial epithelial cells was observed as well as marked keratinization (Gaafar and Al-Mansour, 1981; Duarte *et al*., 2006; Sakae *et al*., 2008). A similar trend of hyperplasia of the epithelium cover of the true vocal folds with disturbed stratification was reported by other researchers (Gaafar and Al-Mansour, 1981; Duarte *et al*., 2006). Epithelial thickening caused by enlargement of basal cells and an increased number of desmosomes and keratinization were also found (Gaafar and Al-Mansour, 1981). Gaafar and Al-Mansour (1981) reported changes to the muscle and nerve fibers. Muscle damage is noticeable by the disappearance of the tonofibrils which are replaced by empty vacuoles. On the other hand, the nerve fibers show collapsing neurotubules and damage to the neurofibrils. This may help explain the hoarseness and fatigue linked with smoking.

An issue that some studies touched on was the dose-dependent morphologic changes to the histology of different levels of the larynx. Duarte *et al*. (2006) studied the histopathological effects on the larynx of rats exposed to cigarette smoke, especially, on the vocal folds. The rats were divided into three groups that were exposed to different doses of tobacco smoke. In the group of 25 days of exposure, no change was observed over the type of epithelium or changes on the lamina propria of the ventral or dorsal areas. However, moderate hyperplasia on the free edge of the vocal folds and a change in the epithelium from cuboidal to squamous were noticed. Also, moderate hypertrophy in the middle portion of the vocal folds close to the arytenoids cartilage was observed. The second group that was exposed to 50 days of tobacco smoke, congested blood vessels throughout the lamina propria were reported as well as the same other histological changes that were present for the first group. The third group that was exposed to tobacco smoke for 75 days showed similar results but did not show metaplasia with keratinization or congested blood vessels. These types of alteration observed were similar to the ones seen in other studies. Previous investigators using three different concentrations of carbon monoxide, observed that hyperplasia and squamous metaplasia in the free edge of the vocal fold was not dosage dependent (Meade *et al*., 1979; Haussmann *et al*., 1998).

Studies that utilizes autopsy to study the effect of tobacco smoking were limited. Nonetheless, they confirmed some of the conclusions of studies conducted on animals. A higher prevalence of histological changes (metaplasia, hyperplasia) were found in autopsied smokers than non-smokers in a study by Feijo' *et al*. as reported by Guimaraes and Abberton (2005). Also, they reported that Muller and Krohn (1980) found that 83% of the autopsied non-smokers had a normal epithelium while only 30% of the heavy smokers did. Gilbert and Weismer (1974) found vocal fold thickening in 87% of smokers as compared with 7% of non-smokers. Additionally, Prout *et al*. (1997) found that most of the observed squamous cell carcinomas of the larynx occurred in persons who had a history of a smoking habit.

Few studies described the macroscopic changes to the laryngeal system due to tobacco smoking. One study explored the effect of smoking on the macroscopic level by means of the vocal fold's macroscopy morphometry. They reported no significant differences between the dimensions of length, width and thickness in smoking and non-smoking male elderly people but a minimally higher than average thickness of the vocal folds in the smoking group compared to the nonsmoking group (Vasconcelos *et al*., 2009). This higher thickness is consistent with results from studies conducted on the microscopic level of the glottis (Gaafar and Al-Mansour, 1981).

Laryngeal tissues when continuously exposed to smoking may undergo more significant changes in addition to hyperemia, edema and pooling of secretions. These changes can result in cancer formation. Cancers are described by the types of cells from which they arise (Hermans, 2012). Most laryngeal cancers are those that start in the squamous cells that cover the surface of the epiglottis, vocal cords and other parts of the larynx and are called squamous cell carcinomas. Cancers that start in the gland cells are called adenocarcinoma. These gland cells are scattered around the surface of the larynx and responsible for producing mucus. Sarcoma, is the cancer that starts in the connective tissue. This type of laryngeal cancer is rare (Yance and Valentine, 1999; Hermans, 2012). In addition to invasive cancers, patients are sometimes diagnosed with precancerous lesions called carcinoma-in-situ (Barnes, 2008). These most commonly occur in the glottis as this area is more likely to produce early signs of the disease. Carcinoma-in-situ occurs when cancerous-like changes happen in the lining of the throat but without any invasion into the deeper tissues (Barnes, 2008). The physiological and functional consequences of laryngeal cancer depend on the type and location of the tumor (Sapienza and Ruddy, 2009). Therefore, there is individual variability of the manifestation of the physiological and perceptual deviations present. It is important to mention that the duration of exposure to cigarette smoke correlates with the severity of these histological lesions (Marcotullio *et al*., 2002; Hamdan *et al*., 2010, 2011).

Pathological changes of the vocal fold: The pathological changes in the larynx were present more often in tobacco smokers than in non-smokers (Krecicki *et al*., 2004). Specifically, organic voice disorders have higher incidence in smokers compared to nonsmokers (Byeon, 2015). The histological changes to different structures of the laryngeal system results in different disorders depending on the affected site (Sapienza and Ruddy, 2009). Smoking is related to different organic disorders such as Reinke's edema, polyps, cysts, granuloma, sulcus vocalis and tumors (Hamdan *et al*., 2010). It is considered to be the main etiological factor in the development of Reinke's edema (Marcotullio *et al*., 2002; Krecicki *et al*., 2004; Hamdan *et al*., 2010). Reinke's edema is a voice pathology that is apparent as swelling due to abnormal accumulation of fluid and it occurs in the superficial lamina propria or Reinke's space (Moore, 1971). This causes a loose appearance of the vocal fold mucosa with extra movement of the cover (Sataloff, 1987). In the endoscopic image, two types of edema could be observed typical edema where a thin layer of mucosa covering space filled with fluid or an edema with visible reddish thickened mucosa with smaller content of fluid. The edematous changes are usually found on the upper side of vocal cords (Krecicki *et al*., 2004).

Although, many voice disorders have been associated with tobacco smoking, research focused on Reinke's edema as the main consequence. However, there are several factors that affect this association between tobacco smoking and Reinke's edema. The presence of laryngeal histological changes seems to be related to heavy and long consumption of tobacco (Guimaraes and Abberton, 2005). Duration of exposure to cigarettes plays an important role in the development of Rinke's edema. Sever manifestations of Reinke's edema appear in individuals who smoked fewer cigarettes per day but have been smoking for a longer time (Marcotullio *et al*., 2002; Krecicki *et al*., 2004). Thus, longer duration of exposure to smoke, results in more histological damage (Hamdan *et al*., 2010) and is directly related to the size of edema (Krecicki *et al*., 2004), leading to more physiological changes. On the other hand, the number of cigarettes consumed daily is related to the clinical appearance and the recurrence of this disease after

management (Marcotullio *et al*., 2002). Other factors were studied in regard to Reinke's edema and smoking. Reinke's edema is more observed in women than in men (Robin *et al*., 2014). In regard to age, there is no relation between patient's age and size of edema (Krecicki *et al*., 2004).

Physiological changes of the vocal fold: The physiology of the vocal folds and the laryngeal system is studied using videostroboscopy. This tool makes a permanent record of the vocal fold structure and function (Focht *et al*., 2013). Several parameters are obtained that include but not limited to glottal closure pattern, supraglottic activity, amplitude of vibration, mucosal wave, periodicity and overall laryngeal function (Sapienza and Ruddy, 2009; Focht *et al*., 2013). Studies conducted to examine the smoker's larynx using videostroboscopic parameters were limited. In one study for Banjara *et al*. (2014) it was reported that edema and erythema were the most common observed laryngeal characteristic using videostroboscopy in smokers. They found a significant relationship between smoking and abnormal vocal fold edge, edema, abnormal mucosal cover and abnormal phase symmetry.

As mentioned earlier, Reinke's edema is a common organic disorder that is associated with smoking. The most important elements of videostroboscopic examination of Reinke's edema are mucosal wave, periodicity and closure of the vocal cords. Increased mucosal wave and asymmetrical and aperiodical vocal folds movement is often present (Krecicki *et al*., 2004; Banjara *et al*., 2014). There are multiple studies that investigated Reinke's edema by means of visualization techniques. Nonetheless, no studies reported different videostroboscopic parameters of Reinke's edema that are solely associated with tobacco smoking.

Since, smoking has several aggressive effects on the vocal tract and larynx. It may lead to irritation, vocal cords edema, hoarseness, coughing, increase of secretion and infections. The changes in laryngeal structure because of cigarette smoking might be expected to change the mass, the elasticity or the compliance of the vocal folds and their vibratory pattern (Moore, 1971; Sorenson and Horii, 1982; Banjara *et al*., 2014). The increased mass and size of the vocal folds causes them to vibrate at a lower frequency (Gonzalez and Carpi, 2004) which in turn affects the acoustical and perceptual characteristics of the smoker's voice.

Acoustical changes of the vocal fold: Past literature shows the attempts of investigators to determine whether tobacco consumption had any effect on voice whether at a relatively early stage of the smoking habit (Gonzalez and Carpi, 2004) or long-term tobacco consumption (Sorenson and Horii, 1982; Tajada *et al*., 1999). Moreover, these studies aimed to quantify this effect by means of objective measures provided by tools that can compute voice parameters.

The histological damage caused by tobacco may be acoustically evidenced by means of several voice parameters. Nonetheless, there are limited scientific studies that examined the effect of smoking on voice. The parameters that seem to be investigated in most studies were the fundamental frequency (f0) (Gilbert and Weismer, 1974; Sorenson and Horii, 1982; Murphy and Doyle, 1987; Lee *et al*., 1999; Gonzalez and Carpi, 2004; Hamdan *et al*., 2010; Chai *et al*., 2011) and jitter percent (Lee *et al*., 1999; Gonzalez and Carpi, 2004), shimmer percent (Gonzalez and Carpi, 2004; Hamdan *et al*., 2010) and Noise to Harmonic Ratio (NHR) (Gonzalez and Carpi, 2004; Hamdan *et al*., 2010). Previous literature suggests that cigarette smoking has a pitch lowering effect due to lowering of the fundamental frequency (Gilbert and Weismer, 1974; Sorenson and Horii, 1982; Tajada *et al*., 1999; Guimaraes and Abberton, 2005). It is believed that the reduction of the mean fundamental frequency of voice associated with smoking is a result of edema of the vocal folds. It is probable that the histological changes caused by tobacco smoke, particularly the swelling and mass increase of the vocal folds, modify their vibratory pattern (Murphy and Doyle, 1987). Consequently, the regularity of vibration is affected. Higher levels of irregularity in smokers compared to non-smokers were reported (Gonzalez and Carpi, 2004; Lee *et al*., 1999). This high irregularity is captured by an increase in jitter percent and shimmer percent which are the acoustic parameters of frequency perturbation and amplitude perturbation (Gonzalez and Carpi, 2004). Although, jitter and shimmer values were higher for smokers they were still within normal limits (Tajada *et al*., 1999) and did not reach statistical significance (Zeitels *et al*., 1997; Gonzalez and Carpi, 2004). The Harmonic-to-Noise Ratio (HNR) did not differ significantly between smokers and non-smokers (Gonzalez and Carpi, 2004; Hamdan *et al*., 2010). On the other hand, Banjara *et al*. (2014) reported statistically significant lower HNR in smokers compared to nonsmokers.

Gonzalez and Carpi (2004) was the only study to look at all of the parameters provided by the Multidimensional Voice Program (MDVP). Their results show that a short duration of the smoking habit, <10 years has a clear effect on some voice parameters. Fundamental frequency parameters, average fundamental frequency (f0), highest fundamental frequency (Fhi) and lowest fundamental

frequency (Flo) were lowered by smoking, mainly in women. Frequency perturbation parameters, jitter percent, fundamental frequency variation (vFo) and Smoothed Pitch Perturbation Quotient (SPPQ) were significantly higher for the smoker participants. And finally, vocal tremor parameters, Frequency Tremor Intensity Index (FTRI) and Amplitude Tremor Intensity Index (ATRI), seem to be significantly increased by smoking in young men.

The f0 trends that were evident were dependent on the vocal behavior used and gender (Guimaraes and Abberton, 2005). For example, smokers showed a significantly lower f0 during sustained phonation by Tajada *et al.* (1999) and during reading by Gilbert and Weismer (1974); in the male group by Sorensen and Horii (1982) and during spontaneous speech for the male group by Sorensen and Horii (1982). Although, the trend a lower f0 for the smokers was still evident, it did not reach a statistically significant difference between smokers and non-smokers in sustained phonation for Sorensen and Horii (1982) during oral reading for the female group by Sorensen and Horii (1982) and during spontaneous speech for the female group for Gilbert and Weismer (1974), Sorensen and Horii (1982). In general, in every speech task, the f0 values for the smokers are lower than the corresponding values for the nonsmokers (Guimaraes and Abberton, 2005). So, the same trends were still evident though they did not reach statistical significance. Guimaraes and Abberton (2005) looked at the effect of smoking in smokers with and without voice problems. These findings agree with Sorensen and Horii (1982) for sustained vowel production in both genders and for oral reading and spontaneous speech in the female group. It is also in agreement with the results by Gilbert and Weismer (1974) for spontaneous speech.

In some studies, the fundamental frequency parameters were affected in women and had a less effect on men (Gonzalez and Carpi, 2004) which contradicts the results of Sorensen and Horii (1982) who concluded that the lowering effect of tobacco smoking in f0 is more evident in men. The number of cigarettes smoked per day displayed an effect on fundamental frequency parameters in the female group (Gonzalez and Carpi, 2004). Also, the thickening of the vocal folds in males which was directly related to the number of cigarettes smoked has the same effect (Gilbert and Weismer, 1974).

Perceptual changes: When a researcher is investigating the effect of a factor such as smoking on voice, the perceptual judgement of how the voice is abnormal and in what way should be examined along other objective measures such as acoustical and aerodynamic analysis. The human ear is the best tool to rate the normal or abnormal quality of a human's voice quality. Nonetheless, reliability of perceptual analysis of the voice is controversial and sometimes the inter-judge agreement among listeners is considered as poor (Oates, 2009). The perceptual measure is subjective and is based on comparison with another voice or with the listener's previous impressions (Lee *et al.*, 2009). The reference levels vary from listener to listener, either in quality or quantity (Bele, 2005; Oates, 2009). As this method of evaluation is subjective, some rating scales such as the "Grade, Roughness, Breathiness, Asthenia, Strain" scale (GRBAS) which was developed by Hirano (1981) have been created to provide a higher reliability in the results.

Perceptual evaluation for smoker's voice was not widely conducted. In one study, quality of voice was perceptually evaluated by using the GRBAS scale (Dedivitis *et al.*, 2004). Five parameters of voice were scored for grade of hoarseness, roughness, breathiness, asthenia and strain according to four-point rating system ranging from 0 (normal) to 3 (severe impairment). The disagreement among the raters was worse for pathological than for normal voices. The best correlation among the raters was found for asthenic voice quality while the roughness was the least consistent factor (Dedivitis *et al.*, 2004).

In some limited studies investigating Reinke's edema caused by smoking, quality of voice was also perceptually evaluated by using the GRBAS scale (Dursun *et al.*, 2007). Nonetheless, the investigators were looking at the improvement in voice quality after surgical intervention and they were not specifically looking at the effect of smoking on voice. Their results showed significant improvement obtained in the GRBAS scores of all patients after surgery. Krecicki *et al.* (2004) used a voice quality scale that holds the following categories: normal voice; discreet changes of voice; hard voice; voice covered, hoarseness; rough voice; hoarse voice; voice barking, pushing, puffing and voice changed on account of the illness. Their results also indicated the improvement of voice quality following surgery but they did not investigate the effect of smoking cessation post-surgery on voice.

RESULTS AND DISCUSSION

Limitations of past literature: Unfortunately, scientific evidence on the effect of smoking on the larynx and voice quality is still limited (Gilbert and Weismer, 1974; Sorenson and Horii, 1982; Murphy and Doyle, 1987;

Tajada *et al*., 1999). The inconsistencies found may be due to certain methodological restrictions that may limit the validity of the findings. The data in most studies was obtained from only an occupational group such as university students or several occupational groups such as secretaries, housewives, nurses and students (Stoicheff, 1975). Moreover, videostroboscopic examination was only performed on participants in a limited number of studies (Stoicheff, 1975; Sorenson and Horii, 1982). Although, tobacco smoking may lead to several laryngeal pathological incidences, the focus of researchers was to investigate Reinke's edema caused by smoking. This indicates a drawback, since, the acoustic/voice quality consequences of smoking on voice depend on the underlying pathological change that took place. For example, when a tumor affects the voice quality or lead to a voice change, it is the size and location of the tumor that determines this change in voice (Moore, 1971). Hence, it could lead to multiple voice changes depending on the nature of the tumor. So, if the exact pathology caused by smoking is not well defined then the acoustic consequences might be misinterpreted if all the participants were assumed to have an edema on the vocal folds.

One other issue that should be kept in mind when interpreting data from these studies is the identification of smoking habit (years, quantity consumed). The cutoff line between early and late stages of smoking was not consistent. Gonzalez and Carpi (2004) considered smoking for <10 years to be an early stage of smoking, although, it was evident from other research that the smoking effect on the tissue begins as early as 25 days of tobacco smoke exposure (Duarte *et al*., 2006). Krecicki *et al*. (2004) drew the line by decade and 20 cigarettes per group, so, group one consisted of individuals who smoked 20 cigarettes for no more than 10 years, the second group consisted of individuals who smoked 20 cigarettes for 10-20 years and finally, the third group consisted of individuals who smoked 20 cigarettes for over 20 years. Although, the researchers defined a more specific criteria for the classification of their subjects, it would still be considered a broad approach to compare changes that takes place between two decades, since, a decade is relatively a long period of time while the changes start to happen as soon as a few days after starting smoking. A finer classification looking at shorter durations might reveal more information in such investigations. The other studies did not take into consideration the duration and amount of consumption of tobacco (Gilbert and Weismer, 1974; Sorenson and Horii, 1982; Murphy and Doyle, 1987; Dedivitis *et al*., 2004; Hamdan *et al*., 2010). Another issue that should be considered when selecting subjects is the administration of a pure tone screening test, since, alterations of auditory sensitivity is known to affect voice characteristics (Summers and Leek, 1998). Only Sorensen and Horii (1982) took that into account.

Studies that investigated acoustic parameters of a smoker's voice focused on changes in fundamental frequency (f0). Although, the same trends were found for the f0 values, some differences were present. Guimaraes and Abberton (2005) reported higher f0 values than these reported by other studies. This could be explained by some methodological differences such as the analysis method used to obtain acoustic parameters. For example, systems more than 20 years old use different mathematical algorithms to obtain the same parameters (Gilbert and Weismer, 1974; Sorenson and Horii, 1982). Furthermore, different analysis systems were used such as Speech Studio from Laryngograph (Guimaraes and Abberton, 2005) and Dr. Speech from Tiger Electronics. Another methodological variability is the distance between the mouth and the microphone used to record the samples for analysis. Some studies did not take that into consideration (Guimaraes and Abberton, 2005). It is known that microphone distance affects the values of jitter and shimmer (Russell *et al*., 1980) which might have had an influence on the analyzed samples.

Restricted sample is another factor that might have affected the results (Guimaraes and Abberton, 2005). Further research documenting objective changes in f0 related to smoking involving a larger sample of speakers will offer more valuable information.

Gender is another factor that might have affected the results in the studies examining acoustic characteristics of the voice of a smoker. Difference in gender effect could be partially explained by the age differences and the distribution of the subjects within the age groups. In Sorensen and Horii (1982), the female subjects were younger than the male smokers. In addition, more than half of the female subjects were in the youngest age group compared with only about one third of the male smokers. This high proportion of younger female subjects might have biased the data toward the values of the nonsmokers rather than away from it. A second explanation might relate to the length of time of smoking and the amount smoked by those subjects. In addition, it may be possible that the female subjects are trying to compensate for the effect of smoking on their vocal characteristics by trying to make their voices higher in pitch.

There are several other issues that need to be considered in future research. It is well known that alcohol (Cooney *et al*., 1998) and caffeine (Akhtar *et al*., 1999) consumption has a similar effect on voice as tobacco consumption. Secondhand smoking is also considered to have a similar effect as mainstream smoking (Gaafar and Al-Mansour, 1981; Lee *et al*., 1999; Isik *et al*., 2004; Duarte *et al*., 2006). Age also has an effect on voice, as with age, pitch tends to get lower. Age was only considered in one study by Sorensen and Horii (1982). Hence, it should be taken into consideration when interpreting data of decreased f0 due to smoking. So, for better results, values should be adjusted for gender, age and durations and frequency of smoking. And confounding factors should be taken into consideration such as environmental smoke and alcohol consumption that may influence the effect of tobacco smoking on voice.

Some unresolved issues may help and give a better indication of how to group or categorize subjects such as the knowledge of how fast the histological alterations happen and are these alterations reversible. This would also give a better insight of what alterations to expect in the voice quality of the smoker.

Effect of smoking cessation: Smoking cessation clearly improves respiratory symptoms and bronchial hyper-responsiveness and prevents excessive decline in lung function (Buist *et al*., 1979). The improvement in lung function was measured in the speed of decline of FEV_1. It was reported by almost all the studies investigating this issue that the accelerated decline in FEV_1 values is slower after smoking cessation (Comstock *et al*., 2008; Buist *et al*., 1976; Tinker *et al*., 1976; Krzyzanowski *et al*., 1990; Xu *et al*., 1992; Scanlon *et al*., 2000; Pelkonen *et al*., 2001; Anthonisen *et al*., 2005). Thus, the decline in FEV_1 is slower in successful quitters than in smokers. Only one longitudinal study using a small number of subjects, showed that FEV_1 improved after smoking cessation (Buist *et al*., 1979) but most studies did not show this (Camilli *et al*., 1987; Lange *et al*., 1989; Townsend *et al*., 1991; Xu *et al*., 1992, 1994; Pelkonen *et al*., 2001). Among sustained quitters, lung function improved more in the first year (Scanlon *et al*., 2000) where the decline in FEV_1 normalizes two years after smoking cessation (Townsend *et al*., 1991).

There are factors that affect these values. It was reported that quitting smoking before the age of 40 was not associated with any loss of FEV_1, however, men and women who stopped smoking between ages 40 and 60 years had FEV_1 levels equivalent to those of persons who are 2-8 years older. Nonetheless, smokers who quit, even after age 60 years have better pulmonary function than continuing smokers (Muller and Krohn, 1980). James *et al*. (2005) reported an age-related decline in FEV_1 that is strongly associated with cigarette smoking. The consistency in the cessation behavior should also be considered. Individuals who attempt to quit smoking and then restart have significantly steeper rates of decline in their FEV_1 than subjects who continue smoking uninterrupted (Sherrill *et al*., 1996).

It is common among quitters to gain weight after smoking cessation. Weight gain had a more negative effect on lung function in men than in women (Wise *et al*., 1998) and as reported by Chinn *et al*. (2005), the lung health study also showed a greater net beneficial effect of smoking cessation in women than in men. Only one study documented the effect of both smoking cessation and weight change on lung function in a general population and the net effect of smoking cessation (Chinn *et al*., 2005). They found a similar net effect of smoking cessation in men and women but a greater decline in lung function due to weight gain in men. This might lead to a conclusion that stopping smoking is more beneficial for women but they assumed that if people who quit are able to maintain their weight, gender differences are unlikely to affect the results. Previous studies of lung function in relation to smoking cessation have not adequately quantified the long-term benefit of smoking cessation. Further research may be warranted.

There are no studies designed to follow smoker's voice after cessation. Nonetheless, the pitch lowering effect of cigarette smoking may be partly reversed after as few as 40 h of smoking cessation as Murphy and Doyle (1987) demonstrated in a study with two subjects. These researchers investigated f0 changes during smoking and no-smoking periods. Voice analyses were performed before, during and after a 40 h period of no-smoking and the results showed a rise in f0 during the no-smoking period (Gonzalez and Carpi, 2004). Although, this type of studies were not conducted on a large number of subjects, it is almost always recommended that cessation of smoking is essential in treating the edema of the vocal folds (Goswami and Patra, 2003; Dursun *et al*., 2007) and preventing the recurrence of this disease after surgical management (Marcotullio *et al*., 2002). Which suggests that cessation of smoking can have a reverse effect on voice.

CONCLUSION

Tobacco smoking is becoming an increasing trend in many cultures. It has adverse effects on health in general and on vocal health in particular. Studies conducted to

investigate the effect of tobacco consumption focused on the histopathological changes on a cellular level as well as changes in physiology and function of both the respiratory and laryngeal systems. Although, various attempts have been made to examine effect of smoking tobacco, they followed different models and sometimes reached contradicting results. From this review we can conclude that more extensive structured studies are needed. To look into the effect of smoking on vocal health, many variables should be systematically controlled in order to get reliable results. Taking into consideration factors such as years of smoking, frequency of consumption and brand of tobacco used. There are other considerations to be made. The production of speech involves the coordinated activity of a number of structures within the vocal tract. Voice also as one component of speech is a complex product that requires integration and coordination of respiration and phonation. Voice is also affected by factors such as gender, age, weight and other phonotraumatic behaviors such as alcohol consumption, allergies and voice misuse. Previous literature did not account for the collective influence of these factors. All elements that affect voice should be examined, so, the specific outcome of smoking can be isolated. The investigation of the effect of smoking on vocal health is one attempt to help smokers speak normally as occupational and social voice users. Therefore, in order to find ways to reverse the damage caused by smoking, one must isolate the consequence of tobacco consumption on voice without the influence of other variables.

In conclusion, in spite of the efforts made to test the effect of smoking tobacco on health, more research is needed to understand the mechanism in which the voice changes solely by smoking and the effect of smoking cessation. This will provide insight on how to help smokers use their optimal voice for communication. Moreover, studies that follow smoking quitters systematically are lacking. Both trends of investigations, for smoking effect and effect of smoking cessation are considered necessary.

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