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The influence of oral cavity tumour treatment on the voice quality and on fundamental frequency

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Abstract

This study aimed to discover whether the surgical treatment of oral cavity tumours only affects on articulation or whether it also leads to a change in voice quality and fundamental frequency. Twelve participants were examined pre- and postoperatively for mean speaking fundamental frequency, standard deviation of the mean fundamental frequency, harmonic-to-noise-ratio and intrinsic pitch. All the parameters showed a substantial postoperative change in some patients.

Keywords: Fundamental frequency, voice quality, oral cavity tumour, head and neck surgery.

Introduction

Carcinomas of the oral cavity represent the forth most frequent types of cancer world-wide for men and the eighth for women. At present, the most common concept of therapy for these sort of tumours is based on tumour resection, oral reconstruction and neck-dissection. Many studies have examined the effects of the resection and the subsequent reconstruction of the structures that have been lost on the ability of the patients to articulate or to swallow (for example, Rentschler and Mann, 1980; Logemann, Pauloski and Rademaker, McConnel, Heiser, Cardinale, Shedd, Stein, Beery, Johnson and Baker, 1993). Until now, not much attention has been given to the influence of voice quality and fundamental

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frequency in the treatment of tumours, despite the fact that impairments of the voice are to be expected in most cases.

Surgery to remove the tumour and subsequent reconstruction can result in significant damage to head and neck muscles. Surgical resection of an oral tumour may result in parts of the tongue or floor of mouth being removed, damaging the intrinsic and extrinsic tongue muscles as well as the suprahyoid musculature. Reconstruction surgery involving the repositioning of the tongue or transplanted tissue may cause further difficulties.

In the case of a neck dissection, lymph nodules and lymph tracts between the shoulder blade and the base of the skull that lead away from the area of the tumour, as well as the surrounding fatty and connective tissue and muscles from either one or both sides of the neck (=neck-dissection), are removed in order to prevent the tumour spreading. The degree of damage to the supra- and infrahyoid laryngeal muscles depends on the extent of the neck dissection.

There is no doubt that the external laryngeal muscles are involved in voice production. The extent and the manner of the influence of the external laryngeal muscles remains unclear and is still the subject of controversial discussion. The general view is that the finer adjustments of the vocal folds are controlled by intrinsic laryngeal muscles, whereas grosser changes require the activation of the extrinsic laryngeal muscles.

It is known that for a normal speaker during sustained phonation, the height of the larynx is usually associated with the fundamental frequency. The vertical movement of the larynx therefore may be a critical component in the control of fundamental frequency, in addition to the cricothyroid muscle (e.g., Vilkman, Sonninen, Hume and Körkkö, 1996).

Several studies seem to confirm that a forward and upward movement of the larynx is connected with an increase in fundamental frequency, while a decrease in fundamental frequency seems to be related to a downward and backward movement of the larynx (e.g., Erickson and Atkinson 1976; Honda, Hirai, Masaki and Shimada 1999). The latter authors explain this by the fact that due to the vertical movement of the larynx the position of the thyroid cartilage in relation to the cricoid cartilage (at the cricoid joint) changes, and this results in varying tension of the vocal cords.

Baer, Gay and Miimi (1976) showed that during complex phonatory tasks such as the change from one register to another, the M. digastricus is active. A number of researchers all reached similar conclusions in their research into the Mm. sternohyoideus and sternothyroideus (Faaborg-Anderson and Sonninen, 1960; Baer *et al.*, 1976; Atkinson and Erickson, 1976; Atkinson, 1978; Erickson and Atkinson, 1976; Erickson, Baer and Harris, 1983; Kori, Sugito, Hirose and Niimi, 1990). They showed that in speaking and singing, the activity of both these muscles increases—most noticeably during extreme lowering or raising of the pitch. Zenker and Zenker (1960), Honda (1983, 1985) and Erickson and Atkinson (1976) also identified a positive phase relationship between the M. genioglossus and the pitch.

It is assumed that a certain biomechanical interaction between the larynx and the supralaryngeal articulators exists (e.g., Whalen and Levitt, 1995; Honda, 1983; Erickson *et al.*, 1983). The supralaryngeal muscles (e.g., Mm. genioglossus, genio-hyoideus, mylohyoideus) are connected via the hyoid bone and the m. thyro-hyoideus with the thyroid cartilage. In the articulation of vowels the posterior muscles fibres of the M. genioglossus raise the back of the tongue and simultaneously pull the hyoid bone forwards.

When the hyoid bone moves forwards, it simultaneously pulls on the thyroid cartilage which in turn moves forward and rotates at the cricothyroid joint in a direction leading to a stretching of the vocal cords, and as a final result the fundamental frequency is raised. This biomechanical connection of the tongue and of the larynx via the hyoid bone is often seen as a plausible causal mechanism of the intrinsic pitch (iF0) of the vowels. Kurita, Uehara, Kojima and Krashina (2002) were able to show that the treatment of oral cavity tumours results in changes in the position of the hyoid bone. They used the pre- and postoperative CT-records of 27 participants with oral cavity tumours to show that postoperatively the hyoid bone moved mainly in an anterior direction. In a more radical resection of the suprahyoidal muscles they were even able to show the existence of a variety of position changes, although the changes in the vertical position were not significant.

The aim of this study was to investigate whether the surgical treatment of oral cavity tumours led to changes in voice quality and fundamental frequency because of the damage to the tongue- and the supra- and infrahyoidal muscles (at the moment of the investigations the participants have not received any radiotherapy). If the position of the larynx is essential to a change in any way at all, the damage to the suprahyoid and infrahyoid muscles (which are generally accepted to be responsible for gross positional changes of the larynx) may lead to limitations in the movement of the larynx itself and as a result the mean fundamental frequency can be influenced. In addition the ability of the voice to modulate can be affected by this damage. Therefore the mean fundamental frequency and its standard deviation was measured pre- and postoperatively. Because changes in the tension relationships of the external muscles can be transfered to tension relationships within the larynx, the harmonic-to-noise-ratio (HNR) was also measured pre- postoperatively to assess voice quality.

The same applies to the intrinsic pitch of the vowels. If the theory that the intrinsic pitch is due to a biomechanical connection between hyoid bone and larynx is correct, then a change in the overall tension relationships between the hyoid bone and the larynx must lead to a positional change of the hyoid bone as well as a change in the iF0.

Method

Subjects

Twelve male patients suffering from tumour of the floor of the mouth and/or tongue for the first time were chosen as participants for this study. They were all German native speakers and had no known neurological complications nor any preoperative voice impairments. All participants underwent a resection of the tumour, a reconstruction and an accompanying bilateral neck-dissection. With the exception of participants 9 and 10, they all underwent a combination of a direct closure of the defect and the insertion of a platysma flap. Participant 9 had no reconstruction at all, in the case of participant 10 a pectoral flap in combination

Table 1. *Overview of participants, showing their age at the time of treatment and the size of tumour according to TNM (TNM = tumour staging classification, with T = size of the tumour, from level 1 to level 4) and the level of severity of their neck-dissection (R = right side, L = left side).*

Participants	Age (years)	Tumour characteristics	TNM	Severity level of neck-dissection
1	45	R anterior floor of the mouth	T2	L:Grade II/R: Grade III
2	53	anterior floor of the mouth	T1	L:Grade I/R: Grade II
3	45	R anterior floor of the mouth	T1	L:Grade I/R: Grade I
4	42	R anterior floor of the mouth	T2	L:Grade I/R: Grade I
5	77	L anterior floor of the mouth	T2	L:Grade II/R: Grade II
6	65	anterior floor of the mouth	T2	L:Grade III/R: Grade I
7	65	R anterior floor of the mouth	T2	L:Grade II/R: Grade II
8	66	tongue	T2	L:Grade I/R: Grade I
9	50	R anterior floor of the mouth	T2	L:Grade I/R: Grade I
10	59	anterior floor of the mouth	T4	L:Grade II/R: Grade I
11	56	tongue	T3	L:Grade II/R: Grade II
13	50	tongue	T2	L:Grade I/R: Grade I

with a platysma flap was performed. With participant 1 the tip of the tongue was reformed with the remaining tissue and the stitching of the rest of the tongue was kept to a minimum. In this study we have roughly divided neck-dissections into three degrees of severity. Grade I includes the removal of the Mm. digastrici and Lig. stylohyoideus, grades II and III additionally include the removal of the m. omohyoideus and the n. ansa cervicalis (innervation of the Mm. sternohyoideus, sternothyroideus and thyrohyoideus).

Table 1 shows the participants' age, the severity of their illness (TNM), the position of the tumour as well as the degree of the neck-dissection (R = right side, L = left side). Participant 10 had the most extensive surgery, followed by participants 11, 1, 6, 5, 7, 13, 2, 8, 4, 9 and 3 (in order of surgical intervention). The operations on participants 8, 11 and 13 were limited to the tongue.

Speech tasks

The participants performed three tasks: read aloud five commonly used words (Kino, Theke, Tuch, Rosi, lang), repeated three times; read a longer text (about 1 minute); and speak spontaneously on a pre-arranged topic (life history or illness description) for about 2 minutes.

Procedure

The acoustic recordings were made shortly before the planned operation and 4–6 weeks postoperatively. The recordings were made with a microphone on a digital audio-tape. No sound-treated room was used for this recording, but the quality of the signal was good enough for analysis. The participants were instructed to speak at a comfortable loudness level.

Data analysis

The Praat 4.0.7 speech analysis program was used for all analyses (http://www.praat.org). The mean speaking fundamental frequency was calculated independently for the read text and for the spontaneously spoken text. The average was calculated from these two values. The standard deviation of the mean fundamental frequency was calculated from the spontaneous spoken text and the read text. The intrinsic pitch was calculated from the segmented vowels [i, a] of the two words—Kino and lang. The average value was determined from the three repeated words. HNR was calculated from the segmented vowels [i, u, a, o, e] of the five words—Kino, Tuch, lang, Rosi and Theke. A paired *t*-test (SPSS) was carried out for the pre-and post-operative values. For the iF0 the distance between F0 /i/ and F0 /a/ was calculated.

Results

Fundamental frequency

In total ten participants had an increase in the mean fundamental frequency post-operatively, whereas only two participants (p3 and p8) showed any decrease. This difference was marked in the case of the majority of the participants. Figure 1 showed the average values that are calculated in semitones (relative to 100 Hz).

Standard deviation

In most cases a postoperative increase in mean fundamental frequency is associated with post-operative increase in standard deviation and vice versa. Two

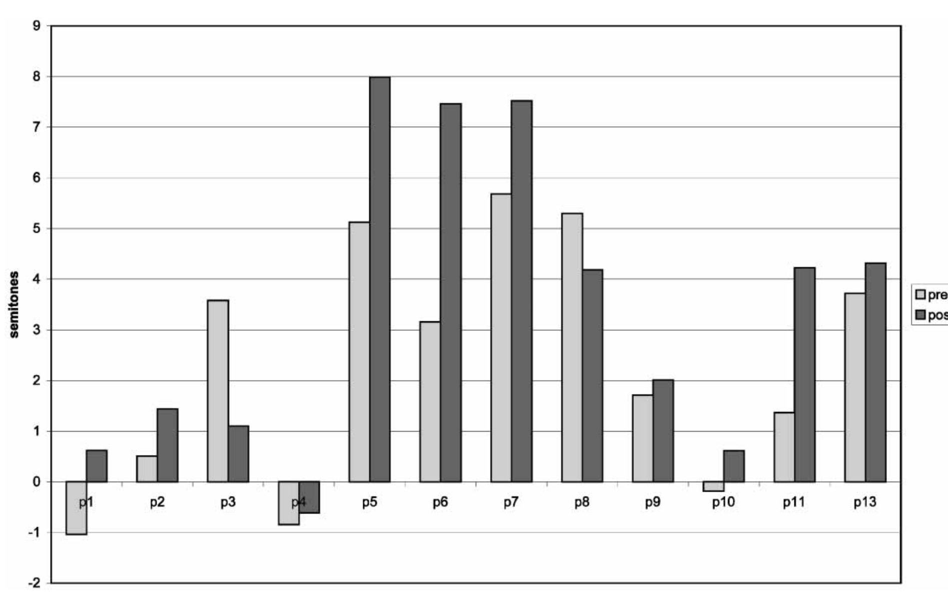

Figure 1. *Average values of the mean fundamental frequency post- and preoperatively for all participants. The results are represented in semitones relative to 100 Hz (0 = 100 Hz).*

participants (p1 and p10) deviate from this trend. In order to obtain a measure that is independent of the mean speaking fundamental frequency, the coefficient of variation (standard deviation/mean speaking fundamental frequency) was calculated for the spontaneous spoken text and the read text. The average was calculated from these two values. In figure 2 this average value is illustrated for all participants.

Seven of the participants (p2, p4, p6, p7, p9, p11 and p13) showed an increase, five participants had a reduction (p1, p3, p5, p6 and p10) of the coefficient of variation postoperatively. These post-operative changes were sometimes substantial (e.g. p4, p6, p7, p10, p11 and p13).

Harmonic-to-noise-ratio

Seven participants (p1, p6, p7, p8, p9, p11 and p13) showed a reduction in the turbulent noise postoperatively when all the vowels are viewed as a whole (mean HNR). For the participants p6, p7, p8, p9 and p11 this reduction was significant (paired *t*-test, $p<0.002$; p9: $p<0.05$; $n=15$).The participants p2, p3, p4, p5 and p10 showed an increase in the turbulent noise when viewed as a whole, but only for participant p4 this increase was significant (paired *t*-test, $p<0.002$, $n=15$).

Intrinsic pitch

It is well known that the fundamental frequency tends to be higher for the vowel /i/ than for the vowel /a/ (intrinsic pitch; cf. Whalen and Levitt, 1995). For this study the distance between F0 /i/ and F0 /a/ was calculated for all participants pre- and postoperatively (figure 3). This distance increased postoperatively for most of

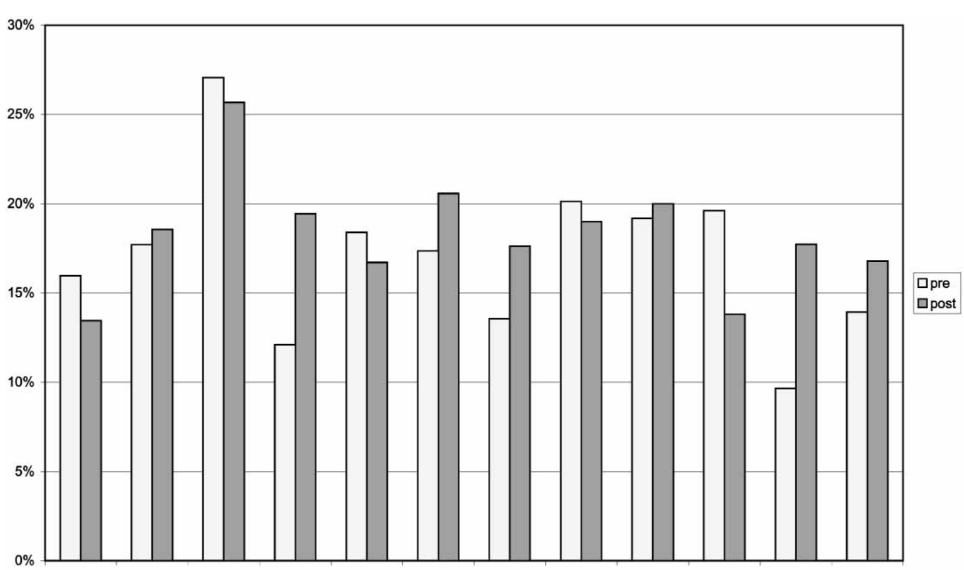

Figure 2. *Coefficient of variation of the fundamental frequency for the read text and the free speech (average) for all participants.*

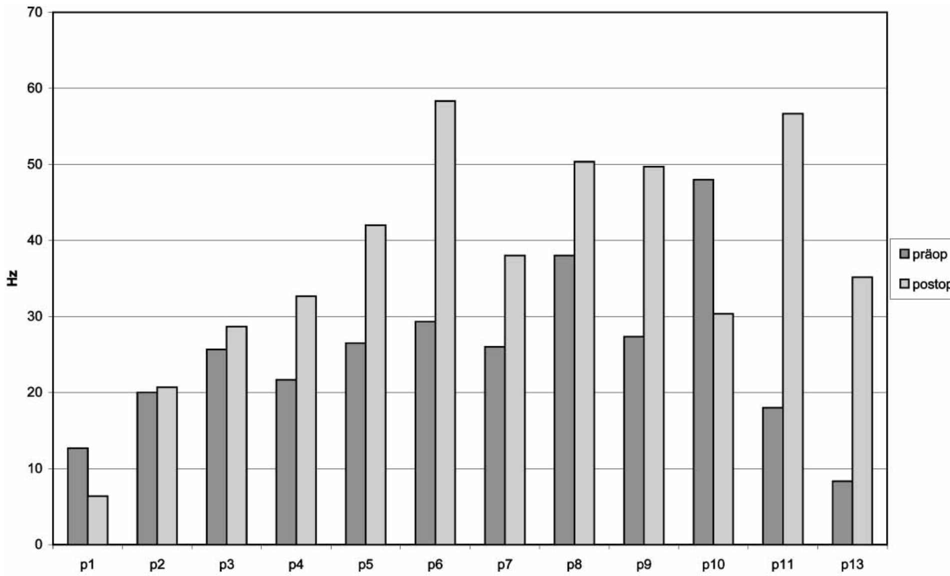

Figure 3. *Distance between F0 /i/ and F0 /a/ for all participants.*

the participants, sometimes substantially (e.g., p4, p5, p6, p7, p8, p9, p11 and p13). For the majority of the participants the reason for this increase was that, within the tendency across all vowels for mean fundamental frequency to increase postoperatively, the changes for the vowel /i/ proved to be much greater than for the vowel /a/.

Discussion

Ten of the 12 participants had a substantial increase in the mean fundamental frequency. Only two participants showed any decrease (p3 and p8). At the same time the turbulent noise as indicated by harmonic to noise ratio decreased post-operatively in most participants. The standard deviation of the mean fundamental frequency (intonational variation in connected speech) was also changed after surgery, in some cases substantial, but there was no prefered direction of change. All these participants showed a change in iF0 that is to say the distance between the F0 /i/ versus F0 /a/ mainly increased post-operatively.

We believe that muscular changes and to some extent considerable damage in the area of the larynx and tongue also altered the tension relationships in the muscles of this area. Because of the partial resection of the intrinsic and extrinsic muscles of the tongue and of the suprahyoidal muscles and the resulting scars in this area and/or the shrinking of the transplanted tissue, the pull on the hyoid bone may have become stronger in the anterior direction; possibly, as Kurita *et al.* (2002) also discovered, the hyoid bone moved forwards. Because of the increased pull on the hyoid bone, the pull on the thyroid cartilage also increased and this in turn can lead to a raised tension in the vocal cords—this raised tension in the vocal cord would lead to an increase in mean fundamental frequency. If the tension did increase, it could result in a better closure or contact between both vocal cords.

The glottal leakage diminishes, and this would lead to a reduction in the turbulent noise.

It is also possible to relate the iF0 which has changed as a result of surgery back to the tension relationships that have undergone changes themselves. In the case that the body of the tongue is displaced forwards and upwards in the mouth which for example can be observed when the vowel /i/ is produced this would lead to a further strengthening of the muscular pull on the hyoid bone and therefore also to a further strengthening of the pull on the thyroid cartilage—this in turn would lead to additional tension of the vocal cords. This would explain why iF0 /a/ showed less change.

It should be noted that the balance between the muscles can be disturbed because of damage to the Mm. sternohyoideus and sternothyroideus, in so far as the estimated antagonistic effect of both muscles is eliminated. The larynx can possibly be pulled forwards and upwards more easily because of the contraction of the suprahyoid muscles. This would also lead to the result already mentioned above.

Of course one should remember that other factors may influence the voice or individual voice parameters. Tumours of the oral cavity are often caused by tobacco and/or alcohol use. The participants were under emotional stress before and after their operations and of course these were performed by various surgeons. All these factors can have had an effect on the parameters that we investigated and cannot be verified here, which is often the case in such clinical studies (Chin and Pisoni, 1995; Klasmeyer and Sendlmeier, 2000). It is also possible that the participants use compensation strategies, e.g., rising of the fundamental frequency, designed to raise the level of understanding.

Conclusion

Further research is essential before the results can be fully assessed. Existing videocinematographic tapes and additional acoustic material will be examined as a next step.

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