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A Cross-Sectional Study on Articulatory Working Space Area in Mandibulectomy or Maxillectomy

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ABSTRACT

Introduction: There has always been a challenge in providing a clear understanding of the critical features of the articulatory movements involved in speech production of individuals who undergo mandibulectomy or maxillectomy. Identifying the articulatory working space area can help the surgeons and the speech pathologists aware of what extend the speech of the patients get affected after surgery. Hence, the present study was aimed at identifying the articulatory working space area in mandibulectomy or maxillectomy.
Methods: Sustained production of vowel /a/, /i/, and /u/ by participants with a digital sound recorder (Sony ICD-PX240 MP3 Digital) kept at a distance of 15cm. Analysis carried out using Praat software (Praat, Version 6.0.21).
Results & Analysis: The formant values obtained for the pre and post-operative groups were statistically analysed using SPSS paired t-test for comparison of pre and post-operative groups, and Independent sample t-test for comparison of control group vs pre/post-operative group. The result revealed a reduced F2 value for the high vowel /i/, reflecting that the anterior movement of the tongue can be restricted due to mandibulectomy. Increased F1 was obtained for the low back vowel /a/ in individuals who underwent maxillectomy, and mandibulectomy indicated reduced mouth opening and reduced elevation of tongue in both clinical groups.
Discussion: Overall, the articulatory working space area was reduced significantly in individuals who underwent mandibulectomy compared to maxillectomy. Thus, when deciding on the prosthesis or reconstructive surgery, efforts should focus on maintaining the coordination and integrity of the tongue and mandible.

Keywords: Mandibulectomy, Maxillectomy, Formants, Vowel Space Area, articulatory working space area, speech

INTRODUCTION

The impact of cancer in the oral cavity on speech depends mainly on the area and size of the growth. Coordination of tongue, lip, jaw, and palate are required for clear speech production. The upper jaw or maxilla contributes towards maintaining the oral and nasal resonance during speech production, whereas lower jaw or mandible forms the base/foundation structure for the movement of all the articulators. [1]

The mandible has been reported as an essential articulator that plays a significant role in mastication, speech, and facial cosmesis. [2] Resection of the mandible either segmental, hemi, or marginal can lead to impaired speech production [3] whereas maxillectomy surgery results in impaired speech intelligibility [4] due to the undesirable coupling between oral and nasal cavities which reduces intraoral air pressure which is required for speech production, thereby leading to

articulatory imprecision, hypernasal speech, nasal air emission, reduced vocal loudness and affecting speech intelligibility.

Speech intelligibility frequently measured by calculating the percentage of correct vowel/consonant production using articulation test and also by percentage of understandability with the help of spoken words by the listeners. The role of mandible or maxilla has not been studied in detail acoustically for its contribution to speech intelligibility. Hence, an acoustic study of their speech is essential to explore its role in speech production. ,

Measurement of formant frequency is one such acoustic analysis that can relate to the movement of the articulators in speech. Formants are the distinguishing or meaningful frequency components of human articulation which reflect the resonance characteristics of the vocal tract. Formants are represented as F1, F2, F3, F4, etc. The first two formants, F1 and F2, are usually used for disambiguating the vowel and determining the quality of vowels in terms of the open/ close and front/back dimensions. [5]

Though there are many speech intelligibility measurement methods available, measuring the vowel space area with formant values was considered to be more apt for the study as it indicates the change in the size of the oral cavity. The size and shape of the oral cavity can be understood by measuring the vowel space area/articulatory working space area with the contribution of F1 and F2 values. Better speech intelligibility is indicated by larger vowel space area, which in turn depicts the larger oral cavity size. The vowel space area is constructed by using vowel formant frequencies which can be used to understand the precision of the articulatory movement and the coordination of tongue and movements. [6]

"Corner vowels", such as /i/, /a/, & /u/ are selected due to its commonness in human languages as they represent extreme positions in a talker's articulatory vowel working space area, and hence extreme formant frequency values in acoustic space. [7] Literature also reported that expanded vowel working space area is observed for clear speech production. [8]

The present study aimed to identify the variations in formants as a reflection of changes in the shape of oral cavity structures due to mandibulectomy or maxillectomy. The study also aims to understand the articulatory working space area or the vowel space area formed by the formants of the vowels for understanding the speech intelligibility in the participants of the study.

MATERIAL AND METHODS

Materials:

Medical and surgical information was collected before recording recommending the speech output from both the groups of participants.

Settings and Design: The present study was a prospective study with cross-sectional study design.

Material used for recording: Sony ICD-PX240 MP3 Digital voice IC recorder. The recorded samples were digitised at a sampling frequency of 44.1kHz and 16 bits/sample quantisation.

Material for Analysis: For speech analysis, the premier software tool, Praat, Version 6.0.21, developed by Paul Boersma& David Weenink at the University of Amsterdam in the year 2016, is used. The analysis is carried out through Dell Laptop with specifications of the processor as Intel(R) Pentium (R) 3558 (U) @ 1.70 GHz. The system is a 64-bit operating system, x 64 based processor.

Procedure:

The participants of the study were instructed to maintain a comfortable sitting posture of a 90-degree angle. Mouth to microphone distance was maintained at 15 cm for all participants.

They were instructed to take in a deep inhalation and phonate vowel /a/, /i/, and /u/ as long as possible at their most comfortable loudness level. Each vowel production was recorded for three times. The presence of

noise in the recording room was monitored on the VU meter of Praat software. Whenever the noise level was observed as high a constant distance of 15 cm was maintained between the recorder and mouth of the patient.

The three trials of phonation sample of /a/, /i/and /u/ was analysed in Praat software for obtaining F1 and F2. The middle of the recorded sample, which was stable, was selected for the analysis. Further Vowel space area or the articulatory working space area was also calculated for all the groups using the formula given by Liu, Tsa&Kuhl, 2005. [7]

Vowel space area = ABS { [F1/i/ * (F2a-F2u) + F1a*(F2u-F2i)+ F1u* (F2i-F2a)]/2} where, "ABS" is absolute value, ''F1i'' symbolizes the F1 value of vowel /i/, ''F2a'' symbolizes the F2 value of vowel /a/ and F2 u represents F2 value of vowel /u/

Participants

The individuals with cancer of mandible/maxilla attending outpatient department of head and neck oncology were the participants of the study. A written informed consent form was obtained from all the participants before beginning the speech recording. The following inclusion, exclusion criteria have adopted to recruit the participants for the study. The recruitment period was six months from September 2019 to February 2020.

Inclusion Criteria:

1. Histopathological confirmation of the diagnosis of maxilla or mandible cancer.
2. Participants should not have had any history of hearing loss.
3. Participants should not have received any treatment for any other oral cancer.

Exclusion Criteria

1. Recurrence of oral cancer
2. Lesion extending to other oral cavity areas
3. History of Neurological problems

The control group selected for the study was based on the inclusion and exclusion criteria such as proficient in Kannada, individual with no history of hearing loss, and between the age range of 20 to 70 years.

The speech recording was carried out for 20 normal's (10 males and 10 females), 5 individuals who had mandibular lesions (3 males and 2 females), and 5 with maxillary lesions (3 males and 2 females). The patient details are mentioned in the following Table 1,

Table 1. Demographic Details of participants with maxillary or mandibular lesions

Sl. No.	Age/ Gender	Site of Lesion	Type of Surgery
1.	57yrs/F	Ca lower lip, alveolus floor of the mouth.	Total mandibulectomy with primary closure
2.	67yrs/M	Right side of the mandible, right retromolar trigone	Segmental mandibulectomy and reconstruction done
3	75yrs/M	Squamous Cell Carcinoma (SCC) right buccal mucosa	Wide local excision with Marginal mandibulectomy and reconstruction with RFGB
4	45yrs/F	Solid cystic lesion on left retro mandibular as well as around ramus of the mandible	Segmental mandibulectomy with PMMC flap reconstruction
5	54yrs/M	Ca right retromolar trigone, right submandibular lesion, metastasis to right buccal mucosa	Right hemi mandibulectomy with PMMC flap reconstruction
6	58yrs/M	SCC of the left nasal cavity	Left infrastructural maxillectomy
7	65yrs/M	Irregular heterogeneous enhancing lesion involving right maxillary sinus with bony destruction	Right radical maxillectomy with free flap reconstruction
8	48yrs/F	Ulceroproliferative growth in the left side of the hard palate	Maxillectomy with excision of only the mucosal margin
9	55yrs/F	Adenoid cystic carcinoma of the left hard palate and tonsilar region	Composite resection with PMMC, through the transoral approach
10.	55yrs/M	Palatal process of the maxilla and hard palate	Partial Maxillectomy with reconstruction

The speech recording of participants with maxillary or mandibular lesion was done on 2 occasions, Occasion one was 1 or 2 days before surgery, and Occasion 2 was 1 to 3 months post-surgery. The speech recording of participants who required to undergo radiation and chemotherapy was done either during the course or beginning

of the treatment, thus reduced the impact of radiation or chemotherapy on oromuscular structures.

Ethics: The study obtained ethical clearance from the medical ethics committee with approval number: KCI/MEC/012/20/August 2019, which was approved on 20/08/2019.

STATISTICAL ANALYSIS:

The statistical analysis was carried out using IBM SPSS version 20. The paired t-test was used to compare values between the pre and post-operative groups. An independent sample t-test was done between the control and the pre-operative group as well as the control group and post-operative group comparison.

RESULT

The current study was intended to study and differentiate the formant frequencies and the articulatory working space area of the individuals whose speech was recorded in pre and post conditions of mandibulectomy or maxillectomy. Further, their acoustic measurements were then compared with their age and gender-matched controls.

Formant Variation among mandibulectomy:

On comparison of the formant values, a statistically significant difference was observed only in the F2 values of /i/ which reflected lower F2 value among males in the post-operative group as compared to the control group. A lower F2 value indicates more backward positioning of the tongue for the production of a high front vowel /i/ in mandibulectomy.

Among females, the F1 value of /a/ was significantly increased among the post-operative group was observed as compared to that of the pre-operative group. An increase in F1 value indicates a lesser elevation of the tongue for the production of /a/. It was also found that there was a statistically reduced F1 value in the pre-operative group as compared to that of the control group for the production of /a/.

Table 2: Depict the formant values in individuals with mandibulectomy on comparison with pre and post-operative condition and with that of the control group for both gender

			Pre	Post	Control	Pre vs Post	Pre vs control	Post vs Control
			Mean ± *SD*	Mean ± *SD*	Mean ± *SD*	p-value	p-value	p-value
Male	F1	/a/	626.94 ± 170.01	589.45± 94.32	714.56 ± 120.51	0.80	0.33	0.13
		/i/	313.32 ± 38.16	300.60 ± 33.88	344.12 ± 76.68	0.69	0.52	0.37
		/u/	322.15 ± 71.61	370.75 ± 49.33	365.82 ± 42.12	0.55	0.20	0.86
	F2	/a/	1215.99 ± 156.89	1232.88 ± 367.21	1257.78 ± 117.89	0.95	0.62	0.84
		/i/	2252.40 ±249.31	1983.17 ±262.80	2386.40 ± 284.81	0.38	0.48	**0.05***
		/u/	845.17 ± 93.41	760.50 ± 89.44	939.62 ± 163.23	0.10	0.36	0.10
Female	F1	/a/	653.47 ±16.17	780.46 ± 10.21	777.82 ± 72.16	**0.02***	**0.04***	0.96
		/i/	393.12 ± 74.05	454.96 ± 58.28	373.27 ± 63.04	0.62	0.69	0.12
		/u/	415.82 ± 39.98	533.11 ± 93.96	430.64 ± 59.70	0.43	0.74	0.06
	F2	/a/	1313.02 ± 251.78	1477.66 ± 312.31	1333.25 ± 103.76	0.16	0.84	0.21
		/i/	2295.81 ± 327.87	2036.83 ± 98.91	2490.98 ± 306.94	0.35	0.43	0.07
		/u/	920.74 ± 17.03	1465.64± 698.64	958.56 ± 137.85	0.46	0.71	**0.02***

F2 value of /u/ in females was significantly increased in post-operative conditions as compared to that of the control group. This reflects a free anterior movement of the tongue and reduced size of the anterior portion of the oral cavity in females who underwent mandibulectomy during the production of vowel /u/. Table 2 reflects the changes in formant values among

individuals who have undergone mandibulectomy.
*p-value less than 0.05, indicating statistical significance

Vowel Space Area (VSA) Variations before and After mandibulectomy:

The below figure 1 and 2 represents the graphical representations of males and females, respectively.

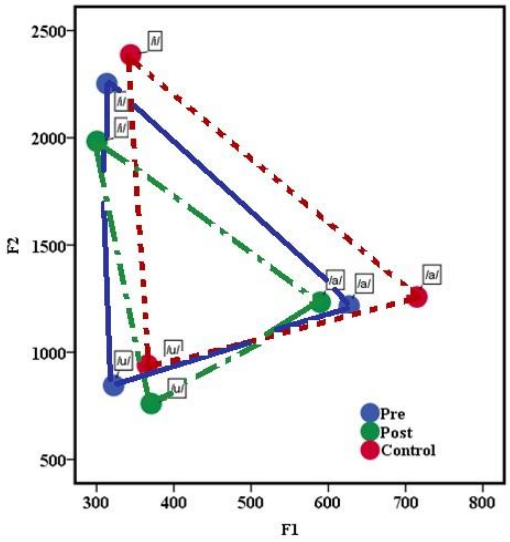

Figure 1: VSA in males pre and post mandibulectomy on comparison with males in the control group

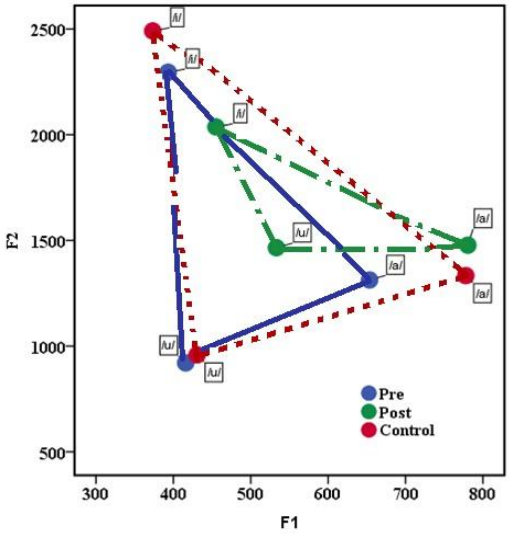

Figure 2: VSA in females pre and post mandibulectomy on comparison with females in the control group

As it is evident for both males and females, there was a reduction in the articulatory working space area in the post-operative group as compared to the pre-operative as well as the control group. The following Table 3, indicates there was a statistically significant reduction in the vowel space area in females who underwent mandibulectomy as compared to the control group. This reflects the finding that females in the post-operative group have reduced speech intelligibility.

Table 3. Vowel Space Area (Hz ^{2}) in individuals with mandibulectomy on comparison with the control group and pre-operative condition

Sl. No.	Gender	Pre	Post	Control	Pre vs Post	Pre vs control	Post vs Control
		Mean ± *SD*	Mean ± *SD*	Mean ± *SD*			
1.	Male	212326.53± 87653.95	137644.53± 45024.58	267028.04± 143056.37	0.35	0.55	0.16
2.	Female	165001.50± 6973.91	97184.13 ±119311.78	274199.15± 85453.58	0.58	0.11	**0.02***

*p-value less than 0.05, indicating statistical significance

Formant Variation among maxillectomy:

Table 4 indicates values obtained in comparison across 3 groups, pre-operative and post-operative group who has undergone maxillectomy and control group. On comparison of the formant values of individuals with maxillectomy, it can be found that only the males had a significant increase in F1 value of /a/ & /i/ in post-operative condition as compared to that of a pre-operative condition. Similarly, among males, the F2 of /i/ was significantly reduced in the post-operative group as compared to that of the control group. Among females, there were no statistically significant differences in pre-operative, post-operative, and control groups.

Table 4. Depict the formant values in individuals with Maxillectomy on comparison with the pre-operative condition, post-operative condition, and control group								
			Pre	Post	Control	Pre vs Post p-value	Pre vs control p-value	Post vs Control p-value
			Mean ± *SD*	Mean ± *SD*	Mean ± *SD*			
Male	F1	/a/	594.93 ± 24.72	639.03 ± 29.76	714.56 ± 120.51	**0.037***	0.125	0.318
		/i/	337.70 ± 30.04	365.13 ± 33.77	344.12 ± 76.68	**0.00***	0.89	0.66
		/u/	351.54 ± 29.13	407.96 ± 7.11	365.82 ± 42.12	0.09	0.59	0.12
	F2	/a/	1131.41 ± 130.41	1247.46 ± 99.38	1257.78 ± 117.89	0.06	0.13	0.89
		/i/	2116.99 ± 83.52	1991.02 ± 274.91	2386.40 ± 284.81	0.42	0.14	0.05
		/u/	826.25 ± 111.02	900.17 ± 106.22	939.62 ± 163.23	0.07	0.29	0.70
Female	F1	/a/	804.26 ± 76.91	724.31 ± 18.68	777.82 ± 72.16	0.30	0.64	0.33
		/i/	422.92 ± 4.34	408.82 ± 29.38	373.27 ± 63.04	0.66	0.30	0.46
		/u/	459.81 ± 7.17	724.31 ± 18.68	430.64 ± 59.70	0.93	0.52	0.61
	F2	/a/	1351.46± 37.25	1324.13 ± 102.79	1333.25 ± 103.76	0.66	0.81	0.91
		/i/	2038.26 ± 159.04	2498.91 ± 85.40	2490.98 ± 306.94	0.22	0.07	0.97
		/u/	999.96 ± 64.06	1049.46 ± 282.38	958.56 ± 137.85	0.80	0.69	0.47

*p value < 0.05, indicates statistical significance

Vowel Space Area (VSA) variation before and after maxillectomy:

There was a reduction in the vowel space area in the post-operative group as compared to that of the control group; however, these values were statistically not significant. This is represented in Table 5.

Table 5. Vowel Space Area (Hz ^{2}) in individuals with maxillectomy on comparison with the control group and pre-operative condition							
		Pre	Post	Control	Pre vs Post	Pre vs control	Post vs Control
		Mean ± *SD*	Mean ± *SD*	Mean ± *SD*			
Maxillectomy	Male	160181.66± 33522.8	137352.66± 66885.16	267028.04± 143056.37	0.47	0.23	0.16
	Female	189269.80± 76998.83	202444.60± 89387.06	274199.15± 85453.58	0.37	0.22	0.30

The following figure 3 and 4 reflect that there was a reduction in the articulatory vowel space area among males and females who underwent surgery. Although the results revealed that the individuals who underwent maxillectomy also had affected speech intelligibility, this difference was statistically not significant.

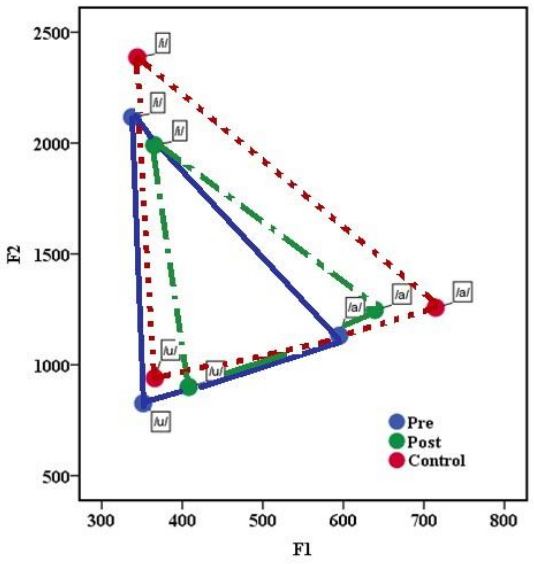

Figure 3: VSA in males pre and post maxillectomy on comparison with males in the control group

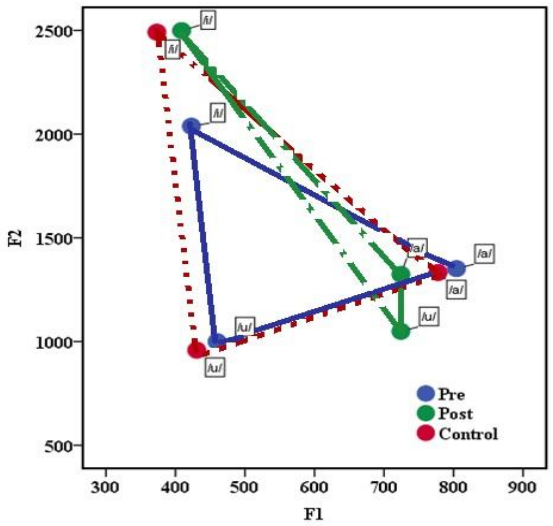

Figure 4: VSA in females pre and post maxillectomy on comparison with females in the control group

DISCUSSION

The present study brings light to the concept that the formant frequency variations be able to reflect the changes in the oral cavity structures. The intact mandible or maxillary structure does play a role in making the speech more intelligible. The results in variations found in formant analysis support the literature evidence that the changes in the position of articulators will be reflected as changes in the formant values. [8] Studies have reported that the analyses of acoustic characteristics are based on the shape and size of the oral cavity, particularly the mandible, maxilla, and tongue. [9]

The lower F2 value of high vowel /i/ among males who underwent mandibulectomy is supported by scientific evidence for the same. [10] They had reported that more significant backward movement of tongue leading to reduced F2 values in individuals' post-surgery of the mandible for management of mandibular prognathism. Thus, the present study echoes the findings that stated F2 is substantially modulated by the anterior-posterior movements of the tongue. [11]

The significantly increased F1 value for the production of /a/ among females who underwent mandibulectomy again reflects a reduced tongue height or an increased patency degree of the lower jaw or mandible. F1 is an indicator of the patency degree of the lower jaw or mandible, and F2 is affected mainly by the movement of the tongue. [12]

Among individuals who underwent mandibulectomy overall, there was a reduction in the vowel space area, which reflects a reduced size of the oral cavity. This points towards the role of the mandible in providing an intelligible speech production. The reduced articulatory working space area can be indicative of inefficient movement of articulators, mainly lip, tongue, and jaw coordination. [13] The vowel working space area reflects the better movement of articulators, mainly for the ease of movement of the tongue within the oral cavity whereas reduced vowel space area may be due to imprecise articulation. [14,15] The vowel working space area can be considered as a measure of the accuracy of vowel articulation, which highlights the gross motor control ability of the tongue and jaw coordination. [16]

Among individuals who underwent maxillectomy, the significant increase of F1 value for production of /a/ and /i/ again reflects reduced tongue height. Moreover, decreased F2 of /i/ also reflects backwardness of tongue movement during speech production. The reduced vowel space area of individuals who underwent maxillectomy also reflects the similar finding of individuals who underwent mandibulectomy. Vowel working space area reflects the better movement of articulators, mainly for the ease of movement of the tongue within the oral cavity, whereas reduced vowel space area may be due to imprecise articulation. [14,15] The study supports the finding that the vowel working space area can be considered as a measure of the accuracy of vowel articulation, which highlights the gross motor control ability of the tongue and jaw coordination. [4,17]

CONCLUSION

The current study highlights the importance of the vowel space area or articulatory space area, which indirectly

reflects the speech intelligibility. Vowel space area which is a motor control ability of individuals who undergo mandibulectomy and or maxillectomy is at risk due to changes in the size and shape of the oral cavity

The strength of the study was the type of study population and utility of acoustic analysis to provide a clear guidance to the maxillofacial surgeons and speech pathologists regarding speech production of mandibulectomy and/or maxillectomy. The limitation of the study was a lesser number of the sample which restricts the generalizability of the result. Another limitation can be a different type of reconstructive surgery which has been included. In future, similar studies can be conducted with a single type of reconstructive surgery.

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