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ORIGINAL ARTICLE

Acoustic Analysis and Speech Intelligibility in Patients Wearing Conventional Dentures and Rugae Incorporated Dentures

Raghavendra Adaki · Suresh Meshram · Shridevi Adaki

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Abstract Phonetics is an important function of oral cavity. It has been overlooked quite frequently while fabricating the complete dentures. In this study modification of anterior palatal surface of denture is done and assessed for its impact on phonetics. Purpose is to assess acoustic and speech intelligibility analysis in edentulous patients and also to evaluate the influence of conventional dentures, arbitrary rugae and customized rugae dentures on speech in complete denture wearers. Ten healthy edentulous patients 55–70 years of age were selected for the study. Dentures were fabricated in conventional way for these patients. Recordings were done for intelligibility and acoustic analysis of the speech. Recordings were done without denture, with conventional denture, with arbitrary rugae denture, with customized rugae denture. Each recording was done at an interval of 10 days period. All four recordings were analyzed and comparison was done using paired '*t*' test. There was significant improvement in frequency peak noise energy for 's', antiformant frequency for 'n' in rugae incorporated dentures. There was relative improvement in frequency peak noise energy for 'sh', frequency proximity burst, voice onset time for 'd', with rugae incorporated dentures. Findings of intelligibility analysis have shown substitution errors with conventional dentures. There was relative improvement of speech with rugae incorporated dentures. Among these, customized rugae dentures showed better results than arbitrary rugae dentures.

Keywords Spectrographic analysis of speech · Arbitrary rugae dentures · Customized rugae dentures

Introduction

Speech is an important function of the stomatognathic system, which uses the oral cavity as an instrument. Teeth, alveolus, palate are static components of speech articulation where as tongue, lip and velum are dynamic components.

Teeth are the important components of speech articulation. Loss of teeth affects the speech articulation and clarity of speech. The change in pattern of speech production is identified as error in speech articulation.

In patients wearing complete dentures, articulatory errors may be due to denture factors like altered vertical dimension, size and position of the teeth, thickness and contour of the denture base.

Scholser and Ghel [1] stated that correction of speech defects due to partial or complete loss of teeth in compliance with phonetic requirement was third major objective for fabrication of denture prosthesis.

Few methods were proposed in the studies to improve the phonetic quality in the denture wearers which includes

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R. Adaki (✉)
Department of Prosthodontics, Bharati Vidyapeeth University Dental College, Sangli 416414, Maharashtra, India
e-mail: raghu_adaki@rediffmail.com

S. Meshram
Department of Prosthodontics, Government Dental College and Hospital, Mumbai, Maharashtra, India

S. Adaki
Department of Oral Medicine and Radiology, Bharati Vidyapeeth University Dental College, Sangli 416414, Maharashtra, India

duplication of palatal rugae, palatographic re-countering of the posterior part of the palate, incorporation of roughness in the anterior part of palate. Rugae and incisive papillae are identified as definitive landmark by tongue. Failure to duplicate them in dentures causes loss of definitive landmarks, leading to farther movement of the tongue resulting in the altered speech.

Pound [2] in 1950 stated that anterior palatal region plays an important role in pronunciation of consonants. He termed it as 'play ground' of tongue because 90 % of tongue's rapid manipulation while talking was restricted to this area and area lingual to lower anterior teeth.

Many contradictory statements were reported in the literature regarding the impact of various anatomic and denture factors on the quality of speech articulation. Landa [3] in 1954 stated that addition of rugae was useless or even detrimental to most of the patients. The additional thickness of the rugae in denture causes phonetic difficulty as tongue prematurely comes in contact with palate. Ylppo [4] in 1955 advised that no loss of tissue has occurred on the anterior palatal region hence denture base should be as thin as possible so that tongue space would be reduced as little as possible.

Considering the above facts, this study was conducted to evaluate the acoustic analysis and speech intelligibility in edentulous patients. The influence the conventional dentures, arbitrary rugae dentures and customized rugae dentures on speech in complete denture wearers was evaluated using sound spectrography for acoustic analysis and intelligibility scale for intelligibility analysis.

Methodology

Ten healthy edentulous patients visiting department of Prosthodontics of Government Dental College and Hospital, Mumbai for complete denture were selected for the study. They belonged to age group of 55–70 years, 9 patients were males and one patient was female. All of them had average ridges and class I ridge relation.

A set of complete denture were fabricated for each patient in conventional way with maintaining adequate vertical dimension and correct centric relation (Fig. 1). On the day of denture insertion patients were taken for speech analysis.

Acoustic Analysis

Acoustic analysis was done in a sound proof air condition room. Patient was seated comfortably on a chair. Microphone was positioned 4–6 inches away from the patient, which was connected to computer in which Praat spectrographic analysis software was installed. List of words

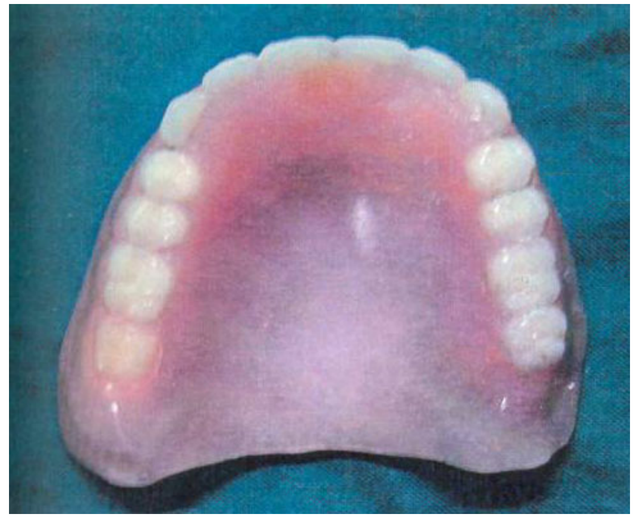

Fig. 1 Denture with polished palatal surface

provided by speech pathologist was given to patient. Patient was asked to read medial consonants and blends. These words were read at an interval of 3 s. From group of the words, particular words and consonants to be studied were isolated. The computerized data of various acoustic parameters was obtained.

Intelligibility Analysis

Similar to acoustic analysis, the audio recording for the intelligibility analysis was done by asking the patient to readout the list of words at an interval of 3 s to maintain uniform space. Later patient was engaged in conversation for 5 min. Conversation was recorded by Sanyo compact recorder. Initial recordings were done without dentures. Then conventional dentures were inserted and asked to report for speech analysis after 10 days. All audio recordings were coded.

Fabrication of Arbitrary Rugae

After the second recording, arbitrary rugae was fabricated by carving incisive papilla like structure lingual to interdental region of central incisors, a straight vertical line of 20–25 mm from incisive papilla and 3–4 horizontal lines on each side of vertical line following contour of the natural rugae (Fig. 2). Patients were asked to wear this denture and to report for recordings after 10 days.

Fabrication of Customized Rugae

Impression of anterior palatal region was made which was used as mold for fabrication of customized rugae. Customized rugae was fabricated on anterior surface of denture using impression as the mold (Fig. 3). Patients were asked to

Fig. 2 Denture with arbitrary rugae

Fig. 3 Denture with customized rugae

wear this denture and asked to report for recordings after 10 days.

All 4 audio recordings were coded.

Cd0 Without denture
Cd1 With conventional denture
Cd2 With arbitrary rugae denture
Cd3 With customized rugae denture

These recordings were analyzed by group of speech pathologists, who were unaware of changes made in denture. Standard intelligibility scale was used for the intelligibility analysis. Acoustic analysis was done using Pratt's software system. Paired '*t*' test was used for comparison. Difference was tested at $P < 0.05$ level.

Results and Discussion

Some terminologies of acoustic analysis are as follows.

Frequency peak noise energy (FPNE) FPNE depends on place of articulation of tongue with palate. As place of articulation of tongue moves forwards, frequency increases.

F1 formant frequency related to supero-inferior position of tongue, F1 varies inversely with tongue height.

F2 formant frequency for vowels related to advancement of tongue, increases as tongue moves forwards.

Antiformant frequency oral cavity is closed at some point for nasal consonants; the frequencies for antiformant are the frequencies at which oral cavity short circuits transmission through nose. General rule is that as a place of articulation moves backwards antiformant frequency increases.

Frequency Peak Noise Energy (FPNE)

FPNE plays more vital role in differentiation of 's' from 'sh' thus it depends on the way tongue articulates with the palate. Normal values [5] for dentate persons are 'sh'—2,500–4,500 Hz and 's'—4,000–8,000 Hz. In this study FPNE for 's' increased from Cd0 to Cd3 and for 'sh' decreased from Cd0 to Cd3 (Tables 1, 2). This shows that pronunciation of 's' and 'sh' were well differentiated in customized rugae denture.

Amplitude of Peak Energy (APE)

APE indicates intensity of sound, which is influenced by the force with which tongue articulates with palate. Normal values [6] for 'sh' are 59–65 db and for's' are 57–68 db. 's' and 'sh' do not differ much in APE. Hence it does not play major role in differentiating 's' from 'sh'. APE was not much different with Cd0, Cd1, Cd2, and Cd3 (Tables 1, 2).

Frequency Proximity of Burst (FPB)

Phonetic identification of noise burst depends on vowel context. This experiment established an important result, namely that stops could be identified solely on the basis of a simplified burst. It also raised the possibility that the phonetic interpretation of the burst was influenced by acoustic context [5].

FPB for 't' decreases from Cd1 to Cd3. This shows that articulation was much posterior with fabrication of rugae pattern.

Word used in this study had a context vowel 'oo' which is back vowel resulting in articulation slightly backward. FPB for 'd' decreased from Cd0 to Cd3, it was least with

Table 1 Results obtained from the acoustic analysis and intelligibility analysis and their inference

Test	Changes observed	Inference
FPNE for 's' and 'sh'	's'—increased from Cd0 to Cd3 'sh'—decreased from Cd0 to Cd3	's' is pronounced more clearly with third denture and most unclear without denture Third denture is better in pronouncing 'sh'
APE	's' and 'sh' do not differ much in APE	Does not play any role in differentiating 's' from 'sh'
FPB for 'T'	Decreased from Cd1 to Cd3	Articulation was much posterior with fabrication of rugae pattern
FPB for 'D'	Decreased from Cd0 to Cd3 and least with Cd2	Pronunciation of 'D' was improved with arbitrary rugae denture, which is better than customized rugae
VOT for 'T'	VOT for Cd0 is more than that with Cd1, Cd2, Cd3.	Pronunciation of 'T' was slurred without denture
VOT for 'D'	Did not change significantly, but least with Cd2	Sharp pronunciation of 'D' with arbitrary rugae denture
Duration of burst	Highest without denture and least with customized rugae	Pronunciation of 'D' was more clear with customized rugae denture
Nasal murmur	Not much significant change in nasal murmur with change in palatal contour	
CFF and CAF	CFF and CAF fall within the range with Cd0, Cd1, Cd2, Cd3, but at the upper limit of range with Cd3.	Articulation was better with customized rugae
Intelligibility	Improved from Cd0 to Cd3	Customized rugae showed promising results over conventional denture

Table 2 'T' values obtained from comparing Cd0, Cd1, Cd2, Cd3

Tests	Cd0 with Cd1	Cd0 with Cd2	Cd0 with Cd3	Cd1 with Cd2	Cd1 with Cd3	Cd2 with Cd3
FPNE[S]	0.511	−0.794	−1.27	−0.519	−1.84	−2.88*
APE[S]	2.46*	1.1	0.604	−0.362	−0.909	−0.594
FPNE[SH]	0.163	0.218	−0.095	0.159	−0.243	−0.364
APE[SH]	1.64	0.316	−0.0632	−0.731	−0.92	−0.433
FPB[T]	1.05	2.19*	2.45*	0.941	1.22	−0.494
DB[T]	−1.35	−1.98	−1.53	0.736	1.16	0.764
VOT[T]	0.865	0.984	1.09	−0.012	−0.008	−0.16
AMPB[T]	0.005	0.947	0.012	0.563	0.013	−0.65
FPB[D]	0.049	1.75	0.594	2.22*	0.46	−1.35
DB[D]	0.951	−0.911	2.63*	0.883	0.977	1.41
VOT[D]	0.186	1.94	−0.469	2.03	−1.29	−2.28*
AMPB[D]	−0.431	0.48	−0.955	0.72	−0.715	−1.47
NM[N]	1.41	−2.97	−0.0808	−3.08	−3.56*	0.321
CAF2[N]	−0.488	1.7	−1.19	1.24	−0.461	−2.3*
CFF2[N]	−0.83	2.18*	−1.06	1.06	−0.725	−3.94

* Statistically significant

Cd2. This shows that pronunciation of 'd' was improved with arbitrary rugae denture.

Voice Onset Time (VOT)

VOT provides information regarding interval between articulatory release of stop and onset of vocal fold vibration. It is a measure of time between supra-glottal event and onset of voicing. For stops, VOT is the interval between release of the stop and the appearance of periodic modulation for a following sound. The relatively late voicing onset for velars indicates that VOT varies with place of stop articulation. The general rule is that bilabials have the shortest VOTs, alveolars have intermediate VOTs, and velars have the longest VOTs [5].

VOT for 'T' for Cd0 is more than that with Cd1, Cd2, and Cd3 that indicates pronunciation of 'T' was slurred without denture. VOT for 'D' did not change significantly, but it was least with arbitrary rugae, suggesting sharp pronunciation of 'D' was with arbitrary rugae denture (Tables 1, 2).

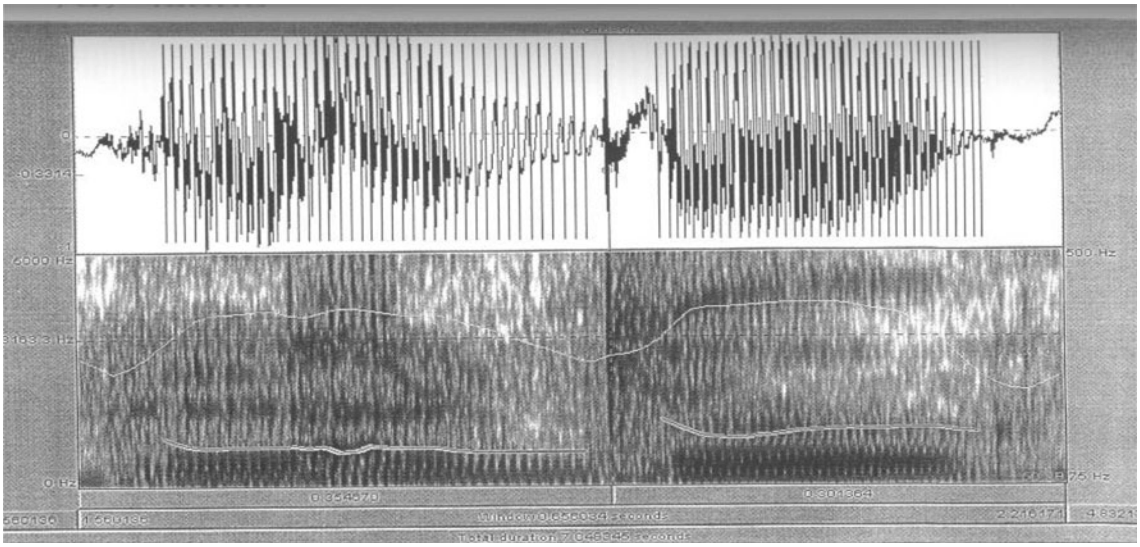

Fig. 4 Spectrograph of 'd' without denture

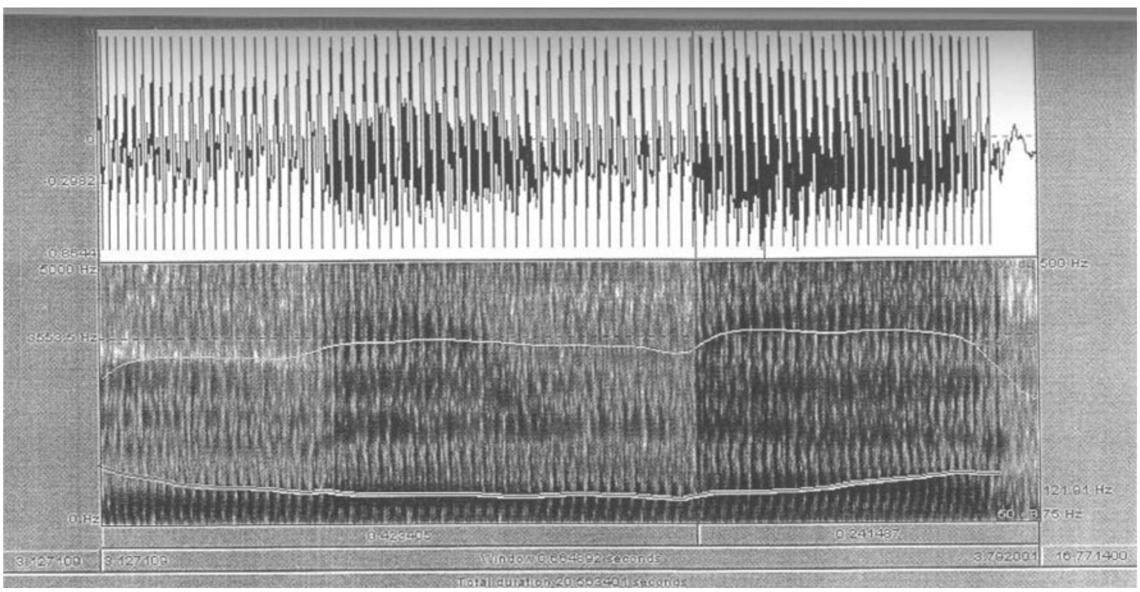

Fig. 5 Spectrograph of 'd' with conventional denture

Duration of Burst

Duration of burst was highest without denture and least with customized rugae denture (Tables 1, 2). This shows that pronunciation of 'D' was much clearer with customized rugae denture (Figs. 4, 5, 6, 7).

Nasal Murmur

The nasal consonants (m, n) in English are produced by closure of the oral cavity and radiation of sound through nasal cavity. The closed oral cavity acts as a shunt or a side branch resonator, which contributes to the resonant qualities of nasal cavity.

The murmur is an acoustic segment associated with an exclusively nasal radiation of sound energy. Nasal murmur is time lag between release of air from nasal cavity and oral cavity.

Perceptual experiments by Kurowski and Blumstain demonstrated that nasal murmur and transition are roughly equal in providing information on place of articulation. Their results also indicate neither murmur nor transition is sufficient for perception of place of articulation.

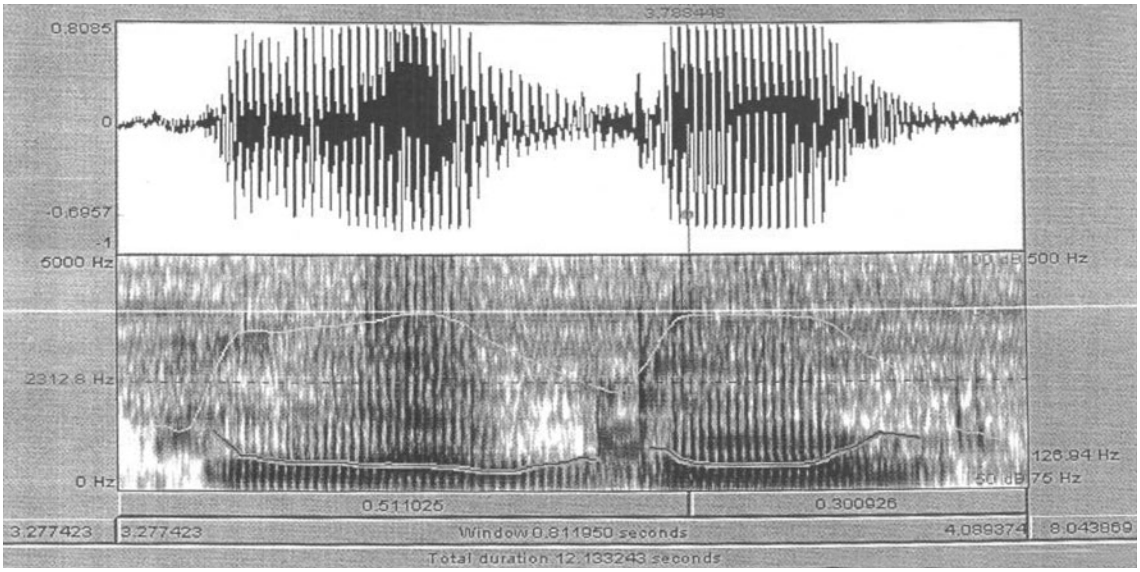

Fig. 6 Spectrograph of 'd' with arbitrary rugae denture

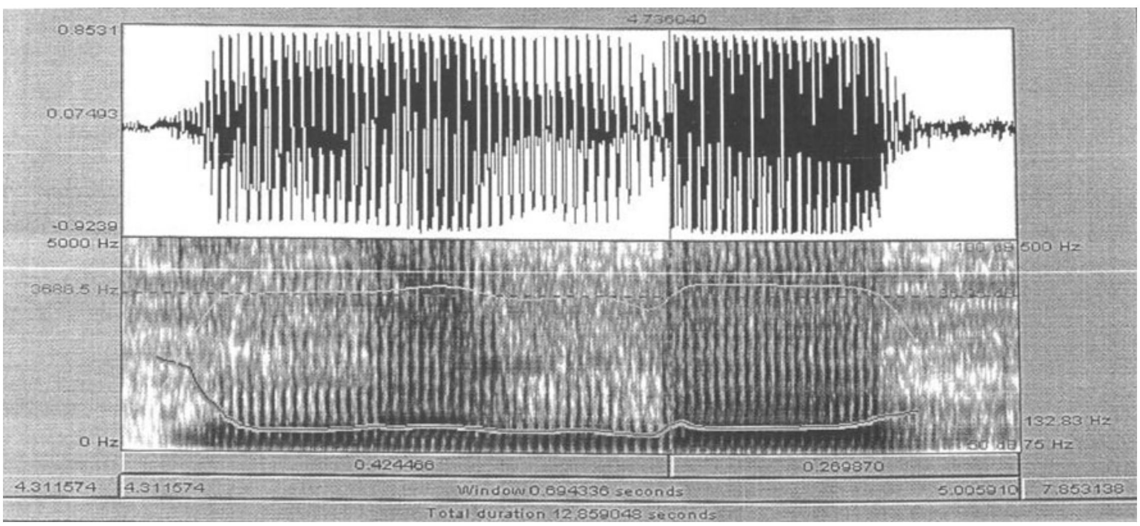

Fig. 7 Spectrograph of 'd' with customized rugae denture

Repp and Svastikale [7] concluded that the vocalic formant transitions by themselves conveyed as information on place of articulation for /m/ and /n/ as did nasal murmur alone.

In this study there were not much significant changes in nasal murmur with change in palatal contour (Table 1, 2).

Central Formant Frequency (CFF) and Central Antiformant Frequency (CAF)

CFF and CAF are related to articulation in oral cavity and are in a range of 1,000–2,000 Hz and 1,450–2,200 Hz respectively. For vowels F1 is frequency of first formant, which varies inversely with tongue height of vowel and F2 is related to tongue advancement and frequency increases as tongue advances forward in oral cavity. General rule is that as the place of oral articulation moves back, frequency of antiformant increases. Both CFF2 and CAF2 fall within the normal range for Cd0, Cd1, Cd2, and Cd3 but with the upper limit of the range for Cd3 suggesting that articulation was better with customized rugae denture (Tables 1, 2).

Thus acoustic analysis shows pronunciation of S, Sh, D, T improved with customized rugae, not much improvement in pronunciation of 'N' which requires more exploration. Amplitude depends on how much force patient exerts while pronouncing particular letter, which in turn depends on circumstances rather than articulation.

Intelligibility

Intelligibility lies within the range of 0–2 (Tables 3, 4). It was improved from without complete denture condition to denture with customized rugae. Two subjects did not show much improvement with change in contour of anterior part of palate. Nevertheless customized rugae showed promising results over conventional denture.

Common errors in articulation with conventional denture and without dentures were substitution of sh by s, t by ta, s by ch, ja by da, t by da, ja by cha, tha by ta, jha by cha. Less aspiration with sh, pha, bha, gha, dha. With customized rugae denture speech was clearer.

Sears [8] recommended making a palatogram in the cases where medial sulcus of the tongue did not coincide with midline of the palate. He suggested grooving of palate just above the median sulcus of the tongue for the patient who had little or no tongue sulcus, thickening of this area for the patient who had a deep tongue sulcus.

Pound [2] improved the quality of the speech by contouring the entire palatal region of upper denture for simulating natural contour.

Palmer [9] from his study indicated that speech quality markedly improved when dentures were incorporated with definitive rugae pattern.

To summarize there is significant improvement in frequency peak noise energy of 's' and antiformant frequency of 'n' in denture with rugae. There is improvement in other parameters also but they are not statistically significant. There are improvements in frequency peak noise energy of 'sh', frequency proximity burst, and voice onset time of 'd', in rugae incorporated denture. Findings of intelligibility analysis have shown substitution errors with conventional dentures. This may be due to lack of rugae, which was identified as definitive landmark by tongue. Tongue articulated with lingual surface of upper anterior teeth instead of anterior palatal region. There is relative improvement of speech with rugae incorporated dentures.

Table 3 Intelligibility analysis

Sample	Cd0	Cd1	Cd2	Cd3
A	1–2	1	1	0–1
B	1–2	1	0–1	0
C	1	1	2	1
D	0–1	0–1	0–1	0
E	1	1	0–1	0
F	1	1	0–1	0
G	1	1	0	0
H	0–1	0	0	0
I	1–2	0	0	0
J	1–2	0–1	0	0

Table 4 Intelligibility rating scale

Description of speech sample	Point scale
Normal	0
Can understand without difficulty. However feel the speech is not normal	1
Can understand with little effort, occasionally need to ask for repetition	2
Can understand with concentration and effort especially by sympathetic listener. Require 2–3 repetition	3
Can understand with difficulty and concentration by family members but not by others	4
Can understand with efforts in content is known	5
Cannot understand at all even when content is known	6

Among rugae incorporated dentures, customized rugae denture showed better results than arbitrary rugae denture.

The results of the study clearly show marked improvement of speech quality in dentures with modified palate. These results are in agreement with results reported by Pound [2], Palmer [9] and others. The results do not show much difference between the arbitrary formed rugae dentures and customized rugae dentures. The arbitrary method of carving rugae if executed properly can improve the quality of speech without much armamentarium, material, time and cost. The frustration and the agony in improving the quality of speech for the people who need it most can be reduced and the patients can be turned into satisfied and happy speakers and singers.

Conclusion

This study was conducted to evaluate the impact of rugae on phonetics. Evaluation of the speech was done by acoustic analysis and intelligibility analysis. Reports of acoustic analysis revealed that pronunciation of 's', 'sh', 't', 'd' was more clearer with rugae incorporated denture than conventional denture. Amongst rugae incorporated dentures, customized rugae dentures were better than arbitrary rugae dentures. Intelligibility reports showed many substitutional errors with conventional denture. With customized rugae denture speech was clearer. Special attention should be given to anterior palatal region while fabricating the denture. Bit of modification in anterior part of palate, which requires minimal amount of time, gives the better results regarding pronunciation, thus enhancing patient's confidence. We can do better justice by inculcating this into our routine practice.

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