FREQUENCY SPECTROGRAPHIC ANALYSIS OF BONE CONDUCTED CHEWING SOUNDS IN PERSONS WITH NATURAL AND ARTIFICIAL DENTITIONS*

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Abstract. Bone conducted chewing sounds picked up by a specially designed device were recorded from three different facial bony locations in two age and sex matched groups of subjects with natural and artificial dentitions. Frequency spectrographic analysis revealed that, although the sounds were louder in subjects with natural dentition, crisp and soggy textures could be equally well differentiated by their noise levels in both groups. The use of a denture adhesive restored the chewing noise of denture wearers to that observed in the natural dentition group. There was a marked degree of mechanical impedance in the transmission of sound from the site of masticatory impact to distant cranial points. Breakdown of particle size during chewing was accompanied by declines in noise levels.

1. Introduction

It has been hypothesized that impairments in the sensory feedback mechanism may be chiefly responsible for the non-preferential chewing pattern in denture wearers, who pulverize particles of all sizes at random, in contrast to the selective pulverization of coarse particles that has been observed in persons with natural dentition (Yurkstas and Manly, 1950; Kapur *et al.*, 1964). Support for this theory was provided by a previous study (Fischer and Kapur, 1966) which revealed that blunted oral sensations, produced by local infiltration anesthesia in subjects with natural dentition, caused a non-preferential pulverization pattern very similar to that observed in denture wearers. Further evidence was gained from the finding that perception of textural characteristics of food in terms of fluctuation in parotid gland response to different textures was markedly impaired in denture wearers (Kapur and Collister, 1970). It was postulated that this handicap resulted from the absence of periodontal mechano-receptors. However, another possible sensory feedback mechanism regulating the parotid gland response to textural stimuli might be in the sounds produced during mastication. A significant correlation was shown between the subjective evaluation of physical characteristics of food and the levels of food crushing sounds (Drake, 1963a, b). Sounds recorded in these studies did not represent the actual vibrations conducted through the bone but rather the vibrations as picked up on the outer surface of the cheek or the air sound in the external auditory canal.

The present study was undertaken with a threefold purpose:

(1) to develop a method which would permit an objective analysis of chewing

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sounds conducted through the bone,

(2) to establish whether this sensory feedback channel is intact in denture wearers, and

(3) to determine whether the use of a denture adhesive affects the characteristics of the transmitted sound.

2. Procedures

A. INSTRUMENT FOR RECORDING AND ANALYZING CHEWING SOUNDS

A two component system was devised for recording and analyzing chewing sounds conducted through the bone. A specially designed 0.0005 in. thick stainless steel needle mounted on a phonograph cartridge (Figure 1) was found to be most reliable for picking up vibrations from bony surfaces while a subject chewed a standard portion

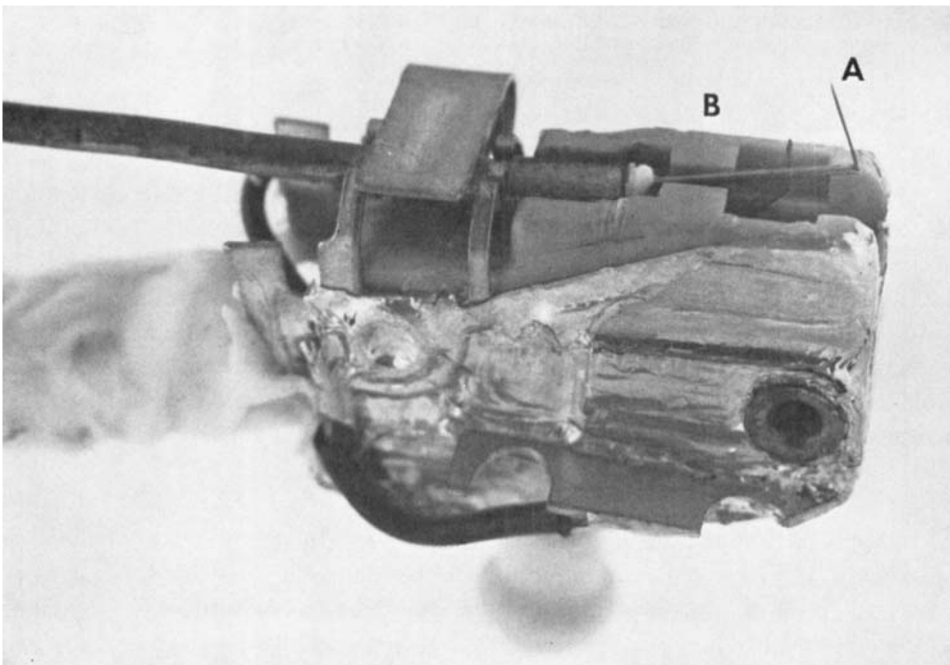

Fig. 1. Sound pick-up device consisting of 0.0005 in. stainless steel needle (A) mounted on a phonograph cartridge (B).

of a test food for 10 strokes. The signal was fed through an amplifier and recorded on a $\frac{1}{4}$ in. magnetic tape in a tape recorder* run at a speed of $3\frac{3}{4}$ in. per sec. The sounds were also monitored with earphones by the investigator.

The data tape was divided into two parts representing the first and the second five chews. Each portion was brought to a standard length of 29 in. by adding a blank

* Bruel and Kjaer, Copenhagen, Denmark, Model 2901.

tape and an endless loop was produced for each portion by splicing the ends. These tape loops were played back at the speed at which they were recorded and the signals were fed through a shielded cable to an automatic audiospectrometer attached to a level recorder.* The audio spectrometer had a total of 31 channels. Twenty-seven of these channels had $\frac{1}{3}$ octave filters and provided response to 27 frequency bands ranging from 40 cps to 16 kcps (preferred numbers) on a logarithmic scale of 0.1. Three networks were weighted to give noise level measurements corresponding to standard noise level meters and the remaining channel gave linear response to the total sound. Switching from one filter to the next was preset at a constant sweep by means of an automatic switch. This, along with the standard length of the tape loop, permitted an integration of the total signal for two complete runs of the loop for each frequency band. The noise intensity was recorded as amplitude on a graph paper run at a speed of 0.3 mm/sec in the level recorder. A complete spectrogram was made in 8 min. With the help of a specially designed transparent template, mean amplitudes for each frequency interval were measured in millimeters from the spectrogram.

B. SELECTION OF SUBJECTS

Two age and sex matched groups of 10 subjects each, one group with complete maxillary and mandibular dentures and the other with natural dentition, were selected. The selection of denture wearers was based on the clinical rating of dentures as 'satisfactory' or 'better' judged by stability, retention, and occlusal relationships of the dentures. In screening the subjects for the natural dentition group, those chosen had to have at least three of the five posterior teeth in occlusion (including abutment teeth for fixed partial denture prosthesis) in the maxillary and mandibular quadrants on the side preferred by the subject for chewing. Also, bilateral occlusal contact in the molar regions was necessary. Subjects wearing removable partial dentures were not accepted.

C. COMPARISON OF SOUNDS FROM DIFFERENT SITES

All subjects participated in this series of tests. Three bony areas (center of the forehead, mastoid process and lower border of the mandible towards its angle) were chosen to establish, if possible, a single satisfactory and reliable landmark for picking up chewing sounds. The pick-up needle was gently pushed through the skin to rest on the bony surface at a point that was free of muscle attachment and had a relatively thin tissue cover. This point was established by palpating the area while the subject was asked to clench his teeth and relax. The pick-up device was held in place with a rubber cuff. The sounds were recorded separately from each of the three sites while the subject chewed a 3 g portion of peanuts.

D. EFFECT OF DENTURE ADHESIVE**

In denture wearers, additional tests were made under two conditions: one requiring

* Bruel and Kjaer, Copenhagen, Denmark, Model 2311.

** Fasteeth, Clark-Cleveland, Inc., Binghampton, N.Y.

the placement of a denture adhesive in the maxillary denture only, and the other in the mandibular denture only. The sounds were recorded from the two sites on the forehead and the mandible, while the subjects chewed a 3 g portion of peanuts for 10 strokes. The sequence of use of the denture adhesive in the maxillary and mandibular dentures was alternated among the 10 subjects.

E. COMPARISON BETWEEN FOOD TEXTURES

Two food textures were tested to compare chewing sounds picked up from the bony sites on the forehead and the mandible. Vanilla wafers, the water content of which had been changed to provide crisp and soggy textures, were employed as the test

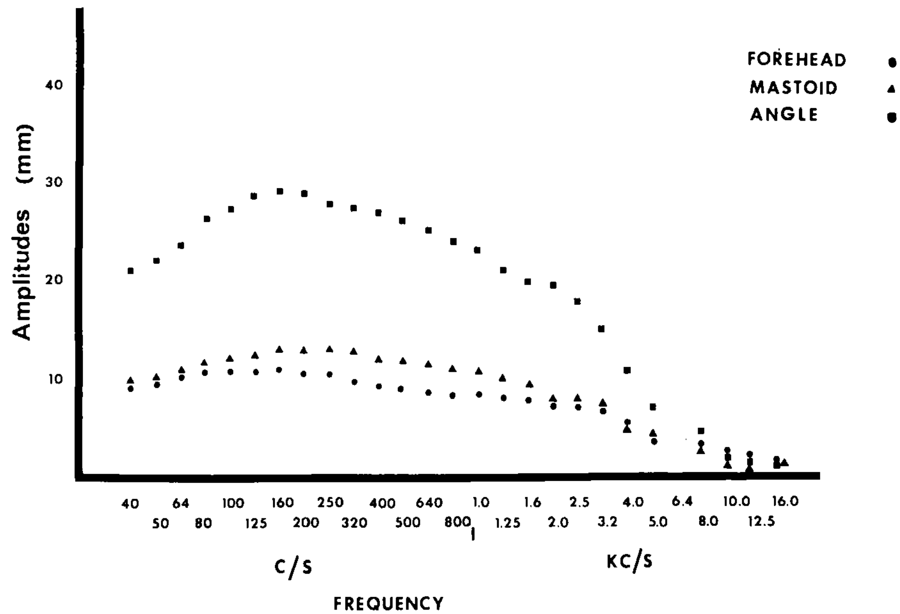

Fig. 2. Amplitude measurements (mm) for different frequencies of the audiograms of sounds picked up at three different bony sites (lower border of mandible, center of forehead and mastoid process) while denture wearers chewed peanuts for the first five strokes.

foods. The sounds were recorded separately from the two sites while the subject chewed each type of wafer 10 times. The sequence of testing of the two textures and the two bony sites was randomized among the subjects in each group.

3. Results

A. COMPARISON OF SOUNDS FROM DIFFERENT SITES

Mean amplitudes of different frequency bands were plotted separately for the sounds picked up from the three bony sites. These values for the first five chews in denture wearers are shown in Figure 2. Sufficient response was found in the region 40–8000cps.

The noise level beyond this range was too low to be measured accurately. Sounds from the angle of the mandible were markedly louder than those picked up from the mastoid process and the center of the forehead. The mandible sounds also consisted of a relatively large component of low frequencies. A more even distribution of the

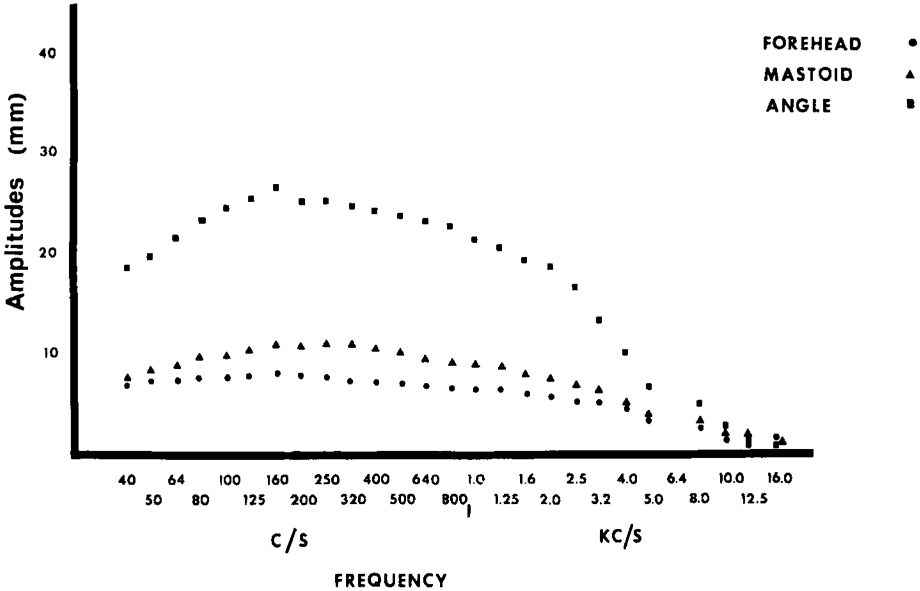

Fig. 3. Amplitude measurements (mm) for different frequencies of the audiograms of sounds picked up at three different bony sites (lower border of mandible, center of forehead and mastoid process) while denture wearers chewed peanuts for the second five strokes.

noise level between the low and the high frequencies was observed in the mastoid and the forehead sounds. In all three slopes, there appeared a slight first order resonance at 2000 cps. The noise level differences between the forehead and the mastoid sounds were small and insignificant.

Amplitude values for the second five chews of peanuts in denture wearers are shown in Figure 3. In general, the slopes for the sounds from the three sites were very similar to those for the first five chews. The peak amplitudes for all three sounds occurred at the same frequencies as did those for the first five chews. However, the noise level amplitudes dropped from 28.5 mm to 26.5 mm for the mandible sound, from 10.4 mm to 7.9 mm for the forehead sound, and from 12.5 mm to 10.5 mm for the mastoid sound. These declines indicated that, as mastication progressed, the structure of the food was gradually broken down.

Amplitudes of the three sounds produced by the first five chews in natural dentition are shown in Figure 4. As in denture wearers, mandible sounds consisted of more low frequencies and were markedly louder (2.5 times or more) than those from the mastoid or the forehead. Although the general slope patterns of each of the three sounds were quite similar to those observed in denture wearers, the noise levels in natural dentition were generally higher for specific frequencies. At the peak amplitude frequency of 160 cps, the noise level was 36% louder for the mandible sound and 42% louder for the forehead sound in people with natural dentition than that in the denture wearers group.

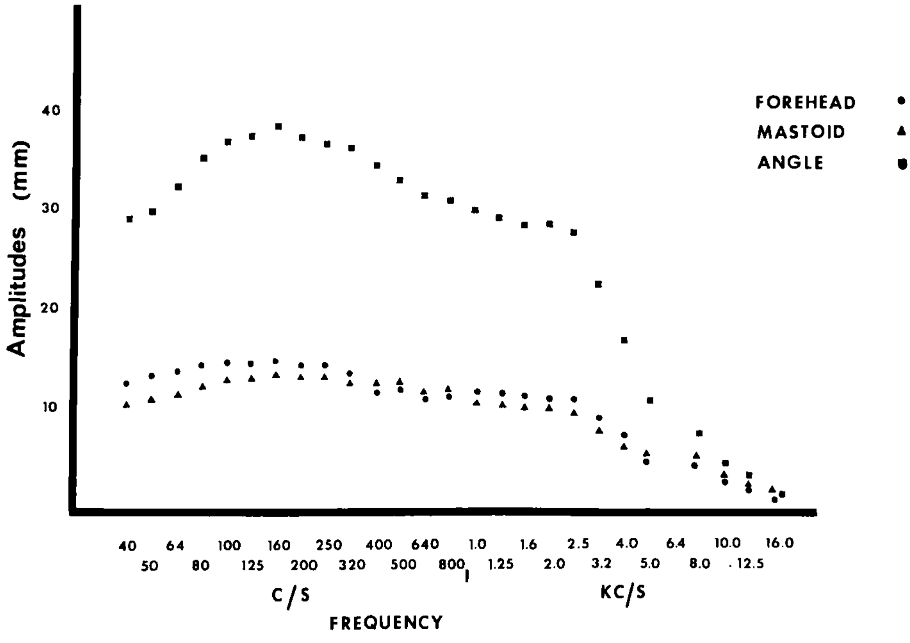

Fig. 4. Amplitude measurements (mm) for different frequencies of the audiograms of sounds picked up at three different bony sites (lower border of mandible, center of forehead and mastoid process) while persons with natural dentition chewed peanuts for the first five strokes.

Amplitude slopes for the second five chews in natural dentition showed greater declines in noise levels from the first five chews than those observed in denture wearers. This indicates that there was greater comminution of peanuts in the first five chews by persons with natural dentition than by denture wearers. In both groups, wide variations in noise levels were found between subjects. However, the peak amplitude frequency remained relatively constant.

B. EFFECT OF DENTURE ADHESIVE

Noise levels of sounds produced during the first five chews by denture wearers with adhesive in either their maxillary or their mandibular denture are shown in Figure 5. Although the general patterns of the audiospectrograms remained unchanged, the use of the denture adhesive increased the intensity of both the mandible and the forehead sounds. The increase in loudness was more pronounced when the adhesive was used in the mandibular denture. The mandible sound also showed a larger gain in intensity over the forehead sound. The use of the denture adhesive in the mandibular

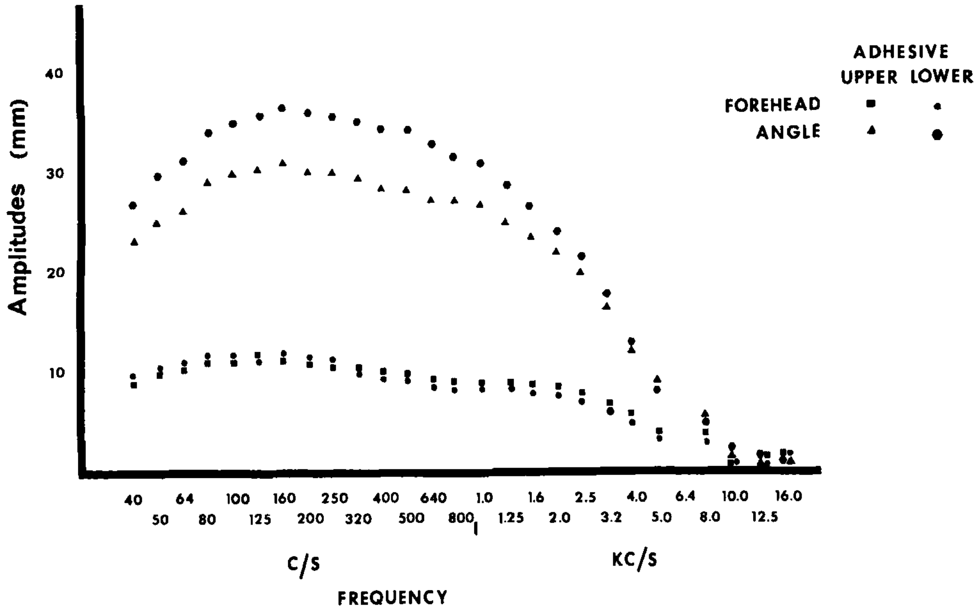

Fig. 5. Amplitude measurements (mm) for various frequencies of audiospectrograms of sounds picked up at two different bony sites (lower border of mandible and center of forehead) while denture wearers chewed peanuts for the first five strokes with dentures which contained denture adhesive either in maxillary or mandibular denture.

denture made the mandible sound almost as loud as the average recorded for persons with natural dentition.

Comparison of amplitude values at the peak amplitude frequency between the natural dentition group and the denture wearers is shown in Table I. In both groups, the peak amplitude frequency was 160 cps for the two sounds. At this frequency, the mean amplitude value of the mandible sound was 38.8 mm for the natural dentition group and 28.5 mm for the denture wearers. Placement of the adhesive in the mandibular denture increased the amplitude by 27% to 36.3 mm, whereas only a 11% increase to 30.6 mm occurred with the adhesive in the maxillary denture.

Loudness of the forehead sound was not appreciably increased with the use of the denture adhesive. Similar results were noted in the spectrograms of the second five chews, including evidence of the test material breakdown which resulted from comminution during the first five chews.

C. COMPARISON BETWEEN FOOD TEXTURES

Intensity levels of sounds produced by crisp and soggy wafers are shown for denture wearers in Figure 6. Sounds produced by crisp wafers were markedly louder (2·2 times or more) than those produced by soggy wafers. This was true for sounds picked up at both the mandible and the forehead. The ratio of noise levels for crisp and soggy foods was about the same for the mandible and the forehead sounds.

TABLE I

Mean peak amplitudes and peak amplitude frequencies for chewing sounds picked up from bony surfaces in artificial and natural dentition groups

Dentition	Natural		Artificial					
			Without adhesive		With adhesive			
					Upper		Lower	
Location	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)
Forehead	160	14.8	160	10.4	160	11.3	160	11.5
Angle	160	38.8	160	28.5	160	30.6	160	36.3

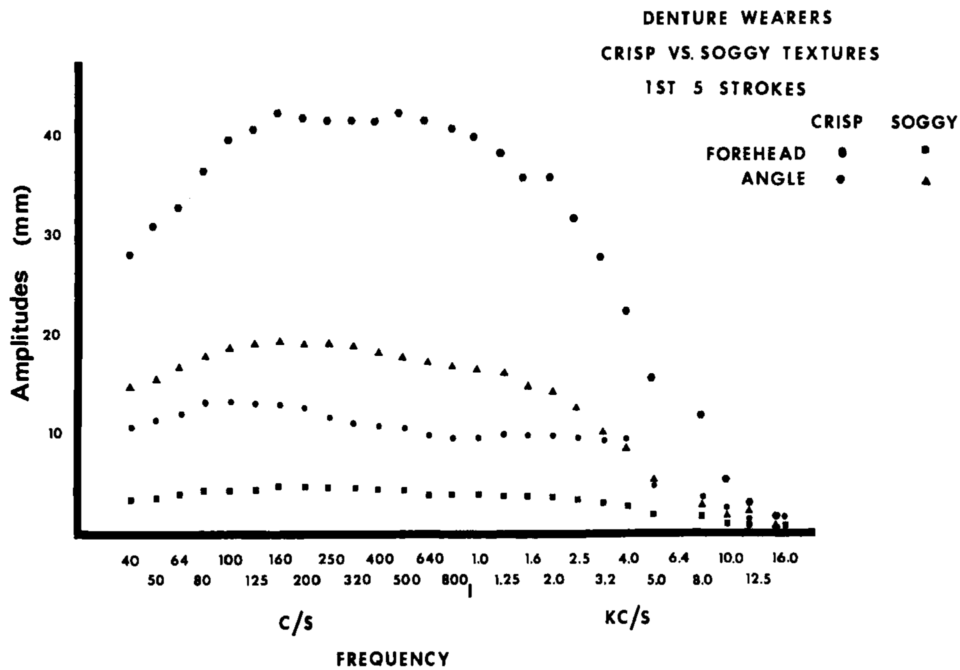

Fig. 6. Amplitude measurements (mm) for various frequencies of audiospectrograms of sounds picked up at two bony sites (lower border of mandible and center of forehead) while denture wearers chewed crips or soggy wafers for the first five chews.

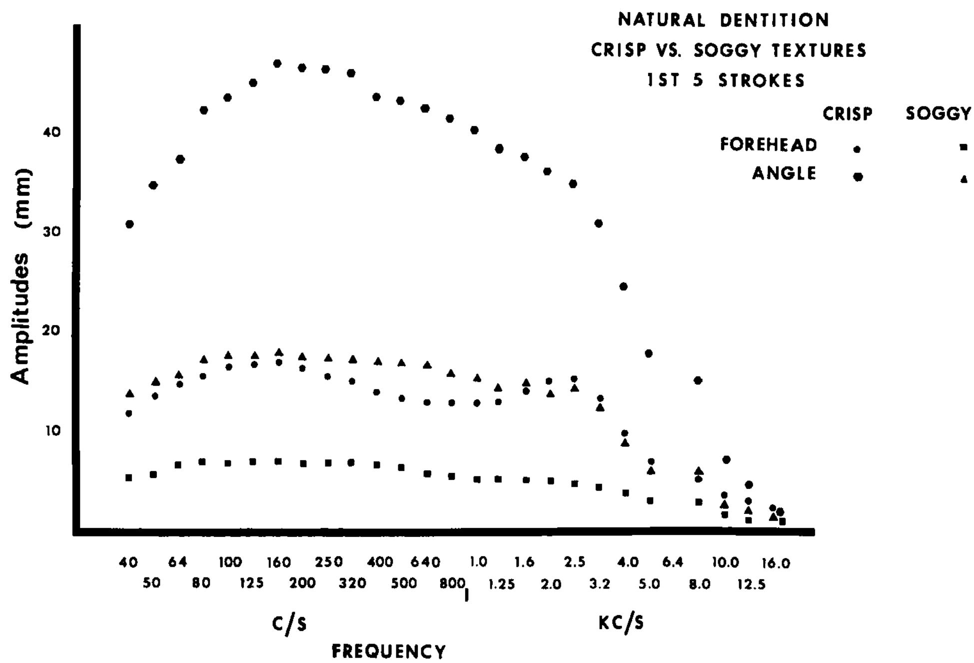

Fig. 7. Amplitude measurements (mm) for various frequencies of audiospectrograms of sounds picked up at two bony sites (lower border of mandible and center of forehead) while persons with natural dentition chewed crisp or soggy wafers for the first five chews.

Amplitude measurements of sounds produced by crisp and soggy textures masticated by subjects with natural dentition are shown in Figure 7. As in denture wearers, louder sounds were produced by crisp wafers. Also, similarly to the results with denture wearers, the ratios of noise levels produced by the two textures remained about the same for both the mandible and the forehead sounds.

Comparison between the two dentition groups of amplitudes at the peak frequency of sounds produced by the two textures is shown in Table II. The peak amplitude frequency remained at 160 cps. The noise levels were 11–50% higher in the natural dentition, except with soggy wafers when the mandible sound was 7.6% lower than the sound in denture wearers. In both groups of subjects, crisp wafers not only produced considerably louder sounds but also showed a more pronounced first degree resonance than was observed with peanuts. These differences in the noise levels of both the mandible and the forehead sounds produced by the two textures were statistically significant ($P<0.01$) in both groups. The noise level differences between the two groups were found to be statistically significant in both the mandible and the forehead sounds produced by the crisp texture, and in the forehead sounds produced by the soggy texture ($P<0.05$).

4. Discussion

The above findings show that textural characteristics of test foods used in this study can be differentiated through the measurement of the noise level of chewing sounds conducted through the bone. Even though these sounds were louder in subjects with natural dentition than in denture wearers, the two textures produced equally distinguishable audiospectrograms. As the two textures produced sounds of different intensities, it is reasonable to assume that these sound differences are perceived in both groups. Therefore, impediment of sound in denture wearers could not be considered as causing the lack of regulation of parotid gland activity observed in response to changes in masticatory texture in an earlier study (Kapur and Collister, 1970). When the amplitude data of this study were related to the parotid gland response levels for the same textures in the two groups of dentition, there appeared to be no relationship between the chewing sound and the parotid gland function. This finding has been further substantiated by the results of another study in which sounds of crisp wafers played back into the ears of subjects chewing soggy wafers failed to influence their parotid gland secretion rates (Kapur, unpublished data). Thus, the parotid gland response to different textural stimuli is regulated by a sensory feedback mechanisms other than the chewing sounds.

As shown in Table II, the intensity of sound detected at the forehead pick-up location was 63–77% less than that detected at the mandible, indicating a loss during transmission. When soggy wafers were chewed, a marked difference in the sound transmission loss occurred between the two groups. For the natural dentition, the loss was 63% while that for the denture wearers was 77%. It is possible that the adhesiveness of soggy wafers produced excessive movements of dentures during

TABLE II

Mean peak amplitudes and peak amplitude frequencies for chewing sounds produced by crisp and soggy textures

Texture	Crisp				Soggy			
Dentition	Natural		Artificial		Natural		Artificial	
Location	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)	Frequency (cps)	Amplitude (mm)
Forehead	160	16.7	160	12.8	160	6.6	160	4.3
Angle	160	47.0	160	42.2	160	17.6	160	19.0

chewing, thereby resulting in diminished continuance of surface needed for better sound transmission. This explanation is further supported by the findings that the use of a denture adhesive, especially in the mandibular denture, almost restored the chewing noise levels of denture wearers to those observed in the natural dentition group. It has been shown that mandibular dentures are relatively less stable and exhibit extensive movement during mastication (Sheppard, 1963).

The recording of sound from three widely situated craniofacial locations provided measurements of actual vibrations transmitted through these points during mastication. As a result, it became possible to determine the degree of mechanical impedance that occurred in the transmission of chewing sounds from a point (lower border of mandible) closer to the site of masticatory impact and shattering of food to two distant cranial points (mastoid process and center of forehead). It was evident that less than 50% of the noise level recorded at the mandible reached the forehead or the mastoid process which is in quite close proximity to the auditory canal. It was also interesting to note that, with one exception, the impedance factor between these landmarks was almost the same in both the natural and the artificial dentition groups.

Acknowledgements

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