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The physiology of the stomatognathic system

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The maintenance or restoration of the normal physiology of the stomatognathic system can best be achieved if procedures are based on a thorough knowledge of normal function.

Because this region is obscured by the overlying soft tissues of the face, investigation has been difficult and incomplete. Furthermore, the problem is one of movement and does not lend itself readily to investigative methods that are essentially static in character, such as anatomic dissection, still roentgenography and checkbites. Yet it is on the necessarily meager information provided by these procedures that presently accepted concepts of stomatognathic physiology are based. Notable exceptions to the use of static methods of inquiry are the work of Hildebrand,[1] of Kurth,[2,3] and of Boswell,[4] all working in the field of jaw movements.

A beginning in the field of cinefluorography for dental investigation was made by Klatsky[5] and by Riesner.[6]

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of the investigation was to determine the facts of the physiology of

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1. Hildebrand, G. Y. Studies in masticatory movement of human lower jaw. Skandinav. Arch. f. Physiol., vol. (suppl.) 1931, p. 3.

2. Kurth, L. E. Mandibular movements in mastication. J.A.D.A. 29:1769 Oct. 1942.

3. Kurth, L. E. Mandibular movements and articulator occlusion. J.A.D.A. 39:37 July 1949.

4. Boswell, J. V. Practical occlusion in relation to complete dentures. J. Pros. Den. 1:307 May 1951.

5. Klatsky, Meyer. A cinefluorographic study of the human masticatory apparatus in function. Am. J. Orthodont. & Oral Surg. 26:664 July 1940.

6. Riesner, S. E. Head and facial pains associated with disturbances of the temporomandibular joints. New York D.J. 13:65 Feb. 1947.

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the region. Since investigation of physiology is essentially a problem of dynamics, it was necessary to explore further stomatognathic function with the tools most suited for the investigation of movement.

Although the entire stomatognathic system came into the investigation, this report deals largely with those aspects of function that involve tooth contact or occlusion. Especially explored was the question of the occurrence and the manner of tooth contact during the act of eating and during swallowing.

DESCRIPTION OF EXPERIMENTS

The action of both the natural dentition (varying degrees of wear) and of the artificial dentition (zero degree cusps to 45 degree cusps) were studied. Thirty-five subjects, of both sexes, ranged in age from 11 to 82 years. In order to eliminate the variables that might have occurred through the use of subjects with preconceived ideas, no dentists or dental students were used in the investigations. For the studies of incision, mastication and deglutition, subjects were given food, then requested only to "eat the food," beginning on signal. Incision, mastication and deglutition were studied only as they occurred naturally during the act of eating. Instructions such as "chew it hard"[7] were purposely avoided because they might introduce a conscious effort that would interfere with and alter the performance of a normal physiologic act. For the studies of the "glide"[2,3] (nonmasticatory grinding[8]), the subjects were instructed to slide the mandibular teeth into protrusive and lateral positions while keeping the teeth in contact.[9]

Since it became apparent early in the investigation that, as previously reported,[10,6] the act of eating varied with the character of the food, studies of the various phases of eating were made with three types of food:

1. Highly resistant food: tough steak, fibrous celery.
2. Moderately resistant food: roast beef, short ribs, crisp apple.
3. Soft food: cheese.

Cinefluorographic studies were made during eating and during the "glide" (nonmasticatory grinding) from both posteroanterior and lateral aspects. During the investigation of mastication, the question of the frequency of tooth contact was explored. Cinefluorography alone proved inadequate for the investigation of this aspect of the problem and it was found necessary to further investigate the frequency of tooth contact and the number of chewing strokes by means of other apparatus which will be described later.

Cinefluorographic studies were made of the action of the condyles during incision, mastication and deglutition, and during the "glide." Opacification of soft tissues was found to be unnecessary for study of tongue and palate, as definition proved to be adequate.

MATERIALS AND METHODS

Cinefluorographic Technic • The apparatus used has been described previously.[11] Cinefluorography was done by radiating through the subject with a 500 milliampere rotating anode tube, to a high intensity fluorescent screen. The screen, encased in a light-proof x-ray table, was photographed by a motion picture camera at the rate of 15 frames per second. In order to gain the greatest length of film without exceeding a radiation limit of 20 r, the camera and x-ray circuit were synchronized through a pulsing device to

7. McLean, D. W. Discussion of V. R. Trapozzano's and J. B. Lazarri's Experimental study of the testing of occlusal patterns on the same denture bases. J. Pros. Den. 2:458 July 1952.

8. Shanahan, T. E. J. Personal communication.

9. Hanau, R. L. Articulation defined, analyzed and formulated. J.A.D.A. 13:1694 Dec. 1926.

10. Wallace, J. S. The physiology of mastication and kindred studies. London, J. & A. Churchill, Ltd., 1903, p. 8, 9.

11. Rushmer, R. F.; Bark, R. S., and Hendron, J. A. Clinical cinefluorography. Radiology 55:588 Oct. 1950.

turn off the x-ray during the time the film was in motion between frames. With roentgen-ray exposure of 200 milliamperes and 100 kilovolt peak at a 40 inch tube-screen distance, a total of seven seconds running time was acquired. The resulting film (Fig. 1) was seven feet long when made with a 35 mm. camera. To allow lengthy analysis of this comparatively short time of action, the individual strips of film were spliced end-to-end, forming a loop that could be run repeatedly through a projector for any desired time. For the purpose of making a demonstration film, such loops were printed on duplication film to give long repetitive runs of each individual strip.

Simultaneous Occlusal Contact and Vertical Motion Graphing • A subject with "normal" occlusion was chosen. It was also necessary that this subject have opposing posterior metallic full crowns. The subject's occlusion was equilibrated to a fine degree. Stainless steel orthodontic bands were fixed to the crowned teeth in a manner to assure definite electrical contact, and extremely flexible 22 gauge stranded plastic-covered copper wire was soldered to the orthodontic bands and carried forward and out of the mouth. The wires were affixed to the buccal surfaces of the teeth in the respective arches in order to avoid interference with normal mastication. Four millivolts was applied to the crowns through the 22 gauge wires and an EKG amplifier (oscillograph) was placed in series with this circuit. The output of the amplifier drove one pen of a multiple channel direct-writing recorder. When the opposing crowns made contact, the circuit was closed and the four millivolts was amplified and recorded graphically as an abrupt deflection caused by sudden excursion or displacement of the galvanometer, which established the fact of absolute occlusal contact. Thus it was possible to establish the frequency of occlusal contact during mastication (Fig. 2).

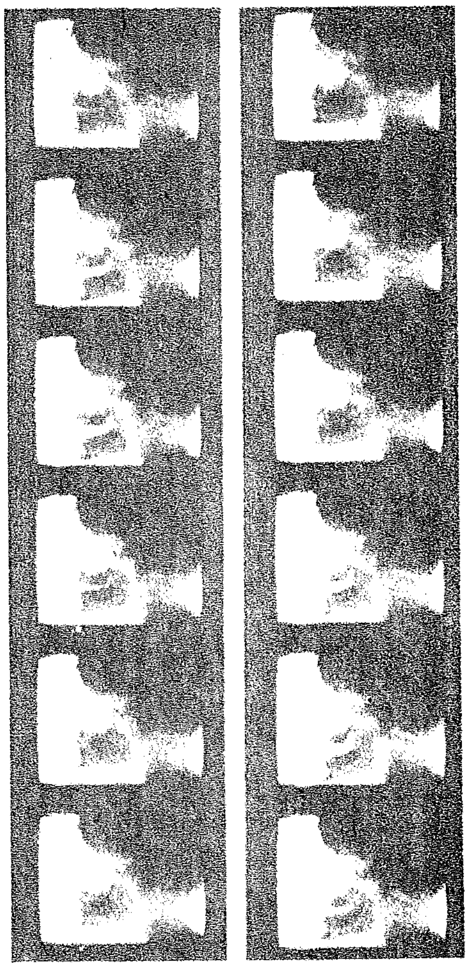

Fig. 1 • Cinefluorographic record of the sequence of events during eating

Method of Recording Vertical Motion Simultaneously with Tooth Contact • An accordion bellows tube was affixed under the gnathion of the mandible and anchored by a strap over the head. The pneumatic pressure within the bellows actuated a strain gauge, the output of which was amplified to drive another channel of the recorder. This assured correlation of vertical motion to occlusal contact (Fig. 2).

The number of subjects analyzed by this method was limited and this is not presented as a complete analysis of the subject.

Report of the Results • Division of the act of eating into incision, mastication and deglutition was purposely avoided during the investigation. This classification is used herewith, however, because of its convenience for purposes of reporting.

INCISION

Incision was investigated by cinefluorography from the lateral and posteroanterior views, and by the stylus graphing originating from the accordion bellows tube and strain gauge, as described earlier. Subjects were requested to "eat the food" so that incision would occur incidentally, as a natural part of the act of eating, and not as a voluntary separate act. A report of performance with each type of food follows.

Highly Resistant Food • The mandible opened, then closed in protrusion, and the food was grasped between the teeth in the protrusive or end-to-end position. When the mandible contacted the food, retrusion of the mandible began, but retrusion stopped when definite resistance was encountered (Fig. 3). Hence incision of extremely tough food often occurred entirely in the end-to-end position. As the mandibular teeth pressed further into the food and muscular tension increased, the movement abruptly changed from an essentially continuous stroke to a movement of rather minute forced oscillations (Fig. 2, 3, 4). Pending further investigation, the true character and significance of this movement must remain in the realm of speculation. All the time that the mandible was cutting into the food and tearing it back toward the centric position, the head and shoulders were rigid or were pulling backward, while the hand and arm twisted the food forward and downward. After the food was torn off with the teeth in the end-to-end position, the mandible dropped, the lips guided the bolus toward the tongue, and the tongue and cheeks placed it between the teeth as the mandible closed to begin mastication.

Moderately Resistant Food • After the mandible had engaged in prehension of the food, movement of the mandible posteriorly toward centric position began. How far toward centric position this movement progressed apparently depended on how rapidly the resistance of the food increased as it was compressed between the teeth (Fig. 2). When moderately resistant food was involved, retrusion was interrupted before the mandible had returned completely to centric position (Fig. 3). Then the short oscillating movements (Fig. 4) began cutting into and thinning the food at that position. The food tore off at the thinned part before the teeth had cut completely through and before contact of teeth occurred. The mandible then opened, the lips guided the bolus toward the tongue, and the lips and the cheek and tongue acted together to place the food between the teeth preparatory to chewing. Participation in the act by the hand and arm, and by the head, neck and shoulders, was evident throughout the act.

Soft Food • The mouth opened, the mandible moved forward and grasped the food in the protrusive position, then sheared into the food moving toward centric position without interruption (Fig. 3). The food was not cut entirely through by the teeth but was parted at the thinned out area.

Discussion of Findings on Incision • It was noteworthy that only with food so soft that the food did not build up pressure as the teeth moved into it, did the act of incision appear as an uninterrupted

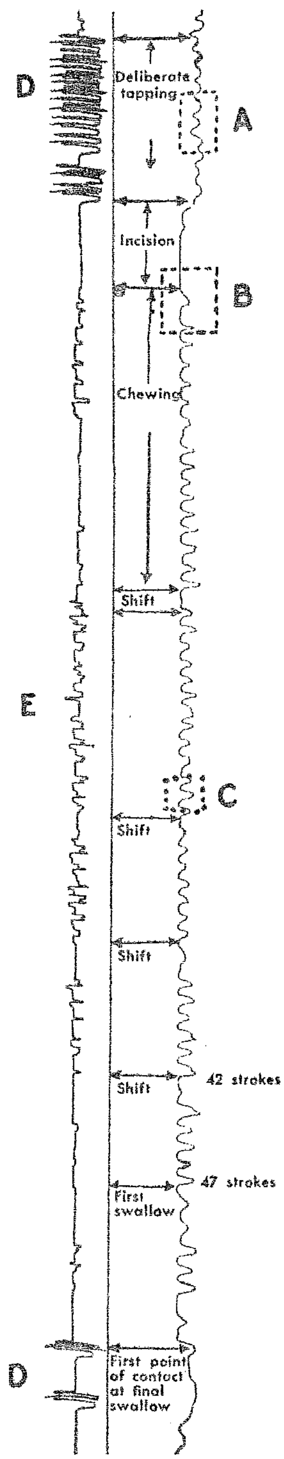

Fig. 2 • Composite graph of vertical motion and tooth contact during eating of crisp apple. A: Strokes during rapid tapping of teeth. B: Incising movement. C: Masticatory cycles. D: Tooth contact deflections. E: Current leakage deflections

shearing or tearing movement toward centric position. The greater the resistance of the food, the sooner progress toward centric position stopped and the relatively continuous stroke changed to the oscillating type. The obvious cutting efficiency of the minute oscillating strokes of this action, and the fact that the action occurred when heavy pressures were necessary to cut into the food, make it likely that they had a cutting function. That they were also a means of control was suggested by the fact that they were equally or more apparent through a much greater range in the incising of a crisp apple, where great pressure was not a factor, but where sudden splitting of the apple necessitated control of movement to avoid sudden heavy shock contact of teeth.

It was plain that incision of food is seldom performed by the teeth alone. The action of the mandibular teeth, grasping the food and tearing and thinning it backwards, was aided by the head and shoulders pulling in the same direction, at the same time as the hand and arm pulled, twisted, and tore the food forward and downward in the opposite direction, until it broke at the portion that had been thinned by the teeth. With resistant, tough fibrous food, the morsel parted where it had become thinner as the teeth cut into it and as the pull of the hand tore and twisted it off while the teeth grasped it between them and held it. With softer foods the movement of the teeth toward centric position contributed a greater proportion of the tearing action. Incision, then, was not a simple act of teeth cutting through food

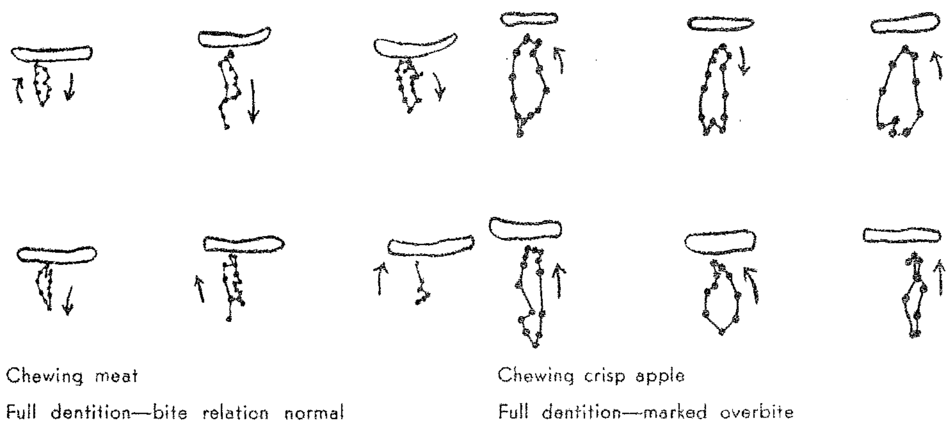

Fig. 5 • Chewing cycles. Dots were traced from consecutive cinefluorographic sequences (posteroanterior aspect). Line between each dot represents 1/15 second of time

MASTICATION

Mastication was studied by:

1. Critical repetitive observation of projected cinefluorographic film in motion.

2. Projecting, one at a time, the successive frames of cinefluorographic strips, and tracing the path of a lead shot that had been placed between the mandibular central incisors just before taking the film.

3. Composite graphing of vertical motion and occlusal contact as already described.

Findings • Critical repetitive observation of the projected moving cinefluorographic film studies was made as a prelude to the detailed analysis reported later.

The path of travel of the mandible as evidenced by tracings of successive frames of cinefluorographic film strip taken from the posteroanterior aspect is shown in Figure 5. Space between each shot represents a time lapse of 1/15 of a second. This interval is an advantage in evaluating speed of travel during the stroke. It is a disadvantage in following a continuous path of travel, however, and allowance should be made for the error it might introduce, especially in the evaluation of the terminal stroke. Kurth reports that, using stroboscopic photographs,[2] 25 visual images per second were necessary for a clear picture of the direction of the mandibular movement.

Cinefluorography alone proved inadequate for the investigation of certain aspects of mastication. Composite graphing of vertical movement and of tooth contact during mastication, as described in an earlier paragraph, yielded much information. A composite graph of a young woman with full natural dentition eating an apple is shown in Figure 2. Tooth relationship was normal and the occlusion was checked for premature contacts. The subject was asked to tap the teeth lightly together and then to eat the apple. The tapping was for the purpose of ascertaining, as a control, the character of the deflection made by the stylus when tooth contact occurred (Fig. 2, D). The small deflections (Fig. 2, E) conceivably made by leakage of electrical current through the apple and saliva are easily distinguishable from those made by tooth contact. In some strokes, as tooth contact was approached, the

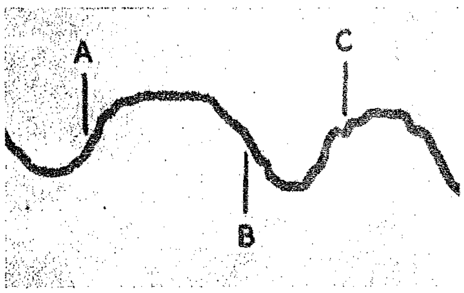

Fig. 6 • Enlarged view of Figure 2, A showing oscillating movement during voluntary tapping of teeth. A: Closing component of masticatory cycle. B: Opening component of masticatory cycle. C: Oscillating movement

graph shows a series of steps (Fig. 6) similar in character to that found during incision (Fig. 4). Occurrence of the oscillating movement during rapid tapping (Fig. 2, A and 6) suggests that it might be part of an involuntary mechanism designed to avoid any shock contact of teeth.

Contrary to the impression that food usually is chewed inadequately in terms of chewing strokes, 54 strokes were made in the chewing of a large bite of apple.

That tooth contact during chewing did not occur, or was insignificant, is evidenced by the absence of a typical tooth-contact deviation on the graph. The characteristic contact deviation (Fig. 2, D), absent during chewing, appeared in some instances at the first swallow, in others only during the second or third swallow. In those instances in which it did not occur during the first swallow, a residual portion of food usually was still between the teeth, even though the main portion which had been manipulated away by the tongue had been swallowed. The residual food was then chewed further for a limited number of strokes and a second swallow occurred. Sometimes food still remained in the mouth, and further chewing and a third swallow was evident.

Discussion of Findings on Mastication • The experimental findings during mastication established the following characteristics of the masticatory cycles ("masticatory cycles" is a descriptive term used by Shanahan[13]).

1. The chewing strokes were not uniform in the closeness of their approach to occlusal contact. The first strokes into a hard resistant bolus terminated far short of occlusal contact; succeeding strokes approached occlusal contact more closely as the bolus was softened and reduced in size.

2. The strokes slowed as they approached occlusal contact.

3. The more or less continuous upward stroke often changed to a controlled oscillating type of movement as tooth contact became imminent. The nature and the significance of the movement is not established.

4. A lateral movement of varying range often was evident at the terminal portion of the stroke. There is insufficient data at the present time on which to base any determination of its nature or function. Whether it is a shearing action as some have assumed[7] or a natural phenomenon of the shift in direction as the opening component of the chewing cycle is approached, or whether it is a combination of both, is not known. Since the lateral movement was equally or more evident in those initial strokes of mastication that stopped far short of tooth contact, the assumption that they represent a shearing movement directed by the inclined planes of the teeth[7] is unwarranted.

5. Even allowing for the 1/15 second time lag indicated in Figure 5, there is a noticeable lack of uniformity of the scope and direction of the terminal lateral movements. The lack of uniformity would

13. Shanahan, T. E. J. Dental physiology for dentures. J. Pros. Den. 2:3 Jan. 1952.

seem to preclude the assumption that this part of the cycle was guided by cuspal inclination.

6. No regular pattern of the chewing stroke was found. Each stroke and each part of the stroke was essentially adaptive to the character of the food being chewed. Furthermore, the character of the food was in a continuous state of change as the mandibular teeth closed into it. The act of chewing was influenced by the constantly changing consistency, shape, and size of the food, by its taste and even by the state of the subject's emotions.[14]

7. The chewing stroke blended into the opening part of the cycle at various levels short of tooth contact. It was apparent that food was between the teeth at all times during chewing, tooth contact being negligible and nonfunctional except as a tactile warning to terminate the stroke.

8. During the opening component of each chewing cycle the cheeks and the tongue maneuvered the bolus into place between the teeth while the mandible dropped into position for the beginning of the next chewing stroke.

Even though it might seem that these findings are incompatible with those of other investigators, they do not detract from the validity of previous reports.[2-4, 7] Important differences in the conditions of the various experiments preclude any likelihood that the investigators were reporting on the same acts. Our report deals with a description of action observed during the uninhibited masticatory function of numerous subjects. Kurth,[2, 3] who has contributed much to this field of investigation, reports on movement made by a subject who

> . . . was first instructed to make free movements of the mandible to the right and left, and to protrude, without using the opening component. . . . Then the patient was told to describe a functional stroke of mastication, the direction of which was determined by the patient's habitual muscular pattern of opening and lateral movement.

Chewing of food was not involved. In justice to this excellent work it must be noted that it was not presented as a study of actual function, but as an illustration of the difference between the stroke and the glide. The findings are valid and well supported. They do not conflict with our findings because they are not descriptive of the same act.

Other findings, which at first glance may seem contradictory to those given here, were recently reported by McLean.[7] He states that the investigation is of a subject chewing Dentyne chewing gum under instruction to "chew it hard." Since the function of chewing is to prepare food for swallowing, the chewing of Dentyne chewing gum is not functional. Furthermore, this substance has few of the characteristics of food while it is being chewed—it does not change volume, its consistency is not affected by the chewing stroke or by ensalivation. The instruction to "chew hard into soft gum" is a directive to the subject to consciously perform the act in a specified way. The findings as reported are valid for the chewing of gum, with specific instruction as to the manner of chewing. Again, they do not conflict with our findings because they are not descriptive of the same acts.

Boswell's[4] concept that the cycles have their termini at centric occlusion is based on findings recorded, during the chewing of various foods, by an ingenious apparatus held in place by an arrangement of straps around the subject's chin and head. The difference in findings could be accounted for by the presence of this device. Boswell's report deals with the performance of subjects wearing this device during chewing; our report deals with the performance of subjects who were not wearing this device during chewing.

14. O'Rourke, J. T. Significance of testing for biting strength. J.A.D.A. 38:627 May 1949.

Again, the findings do not conflict because they are not descriptive of acts performed under the same conditions.

THE "GLIDE" (NONMASTICATORY GRINDING)

Cinefluorographic Findings • Our findings corroborate those of Kurth[2,3] in that we found that the movement of the structures of the stomatognathic system during the "glide" bore no resemblance to the movements occurring during the chewing of food. This observation applies to the action of the teeth, condyles, palate, tongue and hyoid bone. Their relative quiescence in the "glide" compared to the vigorous movements in chewing was especially noticeable. At no time during mastication were we able to detect evidence of the "glide."

DEGLUTITION

Occurrence and Frequency of Occlusal Contact of Teeth • Shown clearly in the oscillograph recording (Fig. 2) is the decisive contact of teeth during deglutition. In the cinefluorographic studies also, closure of the mandible against the maxilla during deglutition was consistently evident. The physiologic necessity for the mandible to be "forcibly anchored in the occlusive position"[15] became apparent when the extremely forceful contractions and thrust of the tongue and suprahyoid muscles were observed. The contraction of these muscles, which have their origin in the mandible, plays a decisive role in the act of deglutition. Stabilization of the mandible against the maxilla allows these muscles to function with the utmost efficiency. No phase of the chewing of food can be accomplished with the teeth in contact because when the teeth are in contact no food is between them.[16] On the other hand, deglutition is performed most efficiently with the teeth in contact, acting as an anchor for the functioning muscles. Shown clearly in Figure 2 is the decisive contact during deglutition, in contrast to the lack of contact during chewing. Indeed, it cannot be stressed too forcefully that it was only during the act of deglutition that functional contact of opposing teeth was demonstrated.

Centric Occlusion During Deglutition • Rushmer[15] reports that

> Efficient deglutition depends on the plasticity and mobility of the tongue. Conformation of the superior lingual surface to the palate forms an air-tight seal which separates the anterior oral cavity from the oropharynx.

This conformation of the tongue to the palate occurred consistently in the cinefluorographic sequences of deglutition. Very consistent, too, was the forceful, piston-like thrust of the tongue as it propelled the bolus into the oropharynx. In short, when swallowing, the scene of action shifted energetically posteriorly toward the pharynx. Forcible retrusion to reach the site of its work, and forcible retrusion to accomplish that work of sealing and of propulsion, characterized tongue action during deglutition. The vigorous retrusion of the tongue (Fig. 7) explains why the mandible was inevitably carried into maximum retrusion during involuntary deglutition whenever the path of closure was free of occlusal interference and clarifies the common observation that in those cases where the mandible is prevented by cuspal interference from attaining centric occlusion, it goes to that position after the interference is removed.

Only during deglutition does tooth contact occur as a functional act. The forceful contractions and propulsive thrusts of muscle groups which have their origin in the mandible necessitate that

15. Rushmer, R. F., and Hendron, J. A. The act of deglutition: a cinefluorographic study. J. Appl. Physiol. 3:622 April 1951.

16. Shaw, D. M. Form and function in teeth, and a rational unifying principle applied to interpretation. Internat. J. Orthodont. 10:703 Nov. 1924.

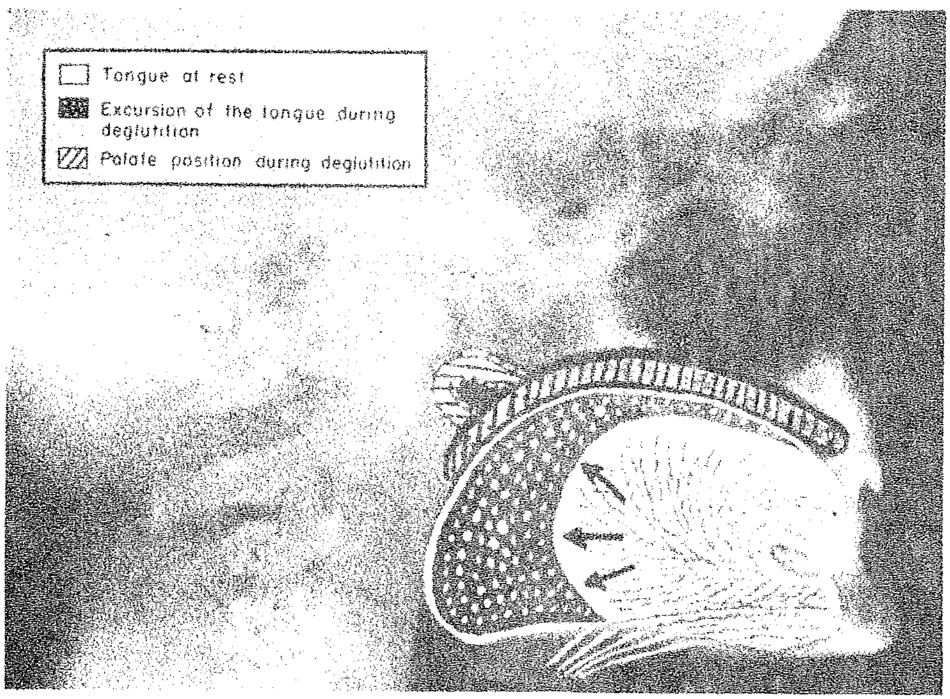

Fig. 7 • Direction and range of movement of tongue during deglutition

the mandible be anchored preferably against the maxilla. Centric occlusion provides this anchorage in the most favorable position for action of the tongue during deglutition. This confirms the almost universal clinical observation of the importance of centric occlusion.

SUMMARY AND CONCLUSION

Cinefluorographic and other investigations led to the following conclusions:

Incision is not a simple act of teeth cutting through food until it is severed. It is a coordinated effort by hand and arm, by teeth, and by head, neck and shoulders. Contact of teeth seldom occurs during the act because the food tears off at the thinned portion before it is cut entirely through. The character of the food being incised greatly influences the nature of the act. The occurrence of minute forced oscillations during incision and mastication is reported for the first time. The nature of these movements and their significance is speculative. Subjects with inadequate denture prostheses compensated for the inadequacy during incision by pushing the food by hand against the maxillary teeth. The mandibular teeth did not participate in the act as cutters. In no case was there any evidence of tooth balance during incision, and tooth balance had no part in the stabilization of the maxillary dentures. The dentures were stabilized by the tongue.

Masticatory cycles are described. The cyclic strokes were adaptive to the food being chewed and exhibited no regular pattern. The findings indicate that food is between the teeth at all times during chewing, tooth contact being negligible and nonfunctional except as a tactile

warning to terminate the stroke. The few light incidental contacts found during chewing seem to be the part of the stroke that "overshot the mark."

The evidence strongly suggests that centric occlusion is the only tooth contact of any significance that occurs during stomatognathic function. Evidence of eccentric tooth balance during eating was not found. There was no evidence that balance of teeth in eccentric positions is a physiologic necessity, or that lack of eccentric balance is less conducive to masticatory function.[17] The voluminous literature on occlusion furnishes little experimental evidence on this question.

17. Burgess, J. K. Discussion of F. W. Frahm's Incisal guidance—its influence in compensation and balance. J.A.D.A. 13:782 June 1926.