MASTICATORY FUNCTION IN MAN

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THE ACT OF CHEWING must be observed to determine how a person masticates. However, this in itself is not sufficient. The actual movements of mastication must be recorded by still and motion picture photography. The records must be made into diagrams which have length, width, and depth. The fourth dimension, the time factor, should be included in some instances.

TYPES OF MANDIBULAR MOVEMENT

A human being is capable of performing two different forms of mastication. The voluntary, gliding, and rubbing motions and the movements of bruxism can be made by almost all people. For example, most can glide the mandible forward, backward, and from side to side with the teeth in contact.

These gliding movements can be produced on most articulators. However, whether these are natural, functional movements remains to be investigated. When a conventional articulator is moved, it follows its normal range of motion and is automatically closed so that the upper and lower teeth touch. The articulator is moved so that the cusps of the upper and lower teeth glide over each other in forward, backward, and side to side directions. These are movements equivalent to human voluntary movements.

Another method of chewing comprises the natural, functional chewing movements. These movements take place predominantly in a vertical direction and differ from the voluntary rubbing movements. Transographics is based upon the concept of a difference between the voluntary rubbing movements and the natural, vertical, functional chewing movements.

APPARATUS AND REQUIREMENTS

Still and motion picture photography was used in this investigation. The masticatory testing apparatus itself presented many difficulties and was changed as the study progressed (Figs. 1 and 2). Essentially, the apparatus was constructed so as not to interfere with the natural chewing act.

The subject's head was stabilized during the chewing tests. However, if the head was held too rigidly, the chewing movements would assume an artificial character. But if the head was not held rigidly enough, the chewing diagrams would contain many errors and could not be correctly superimposed.

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*Clinical Professor.

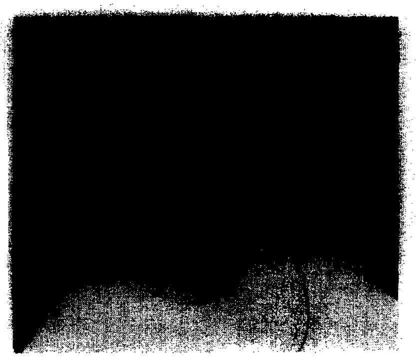


Fig. 1.—A headband and glass plate are attached by universal joints. A grid is marked on the glass plate, which is movable in three planes. The stylus is attached by bands to the lower incisors and carries a small electric light controlled by the subject. Movements of the mandible are recorded in either a dark or light room.

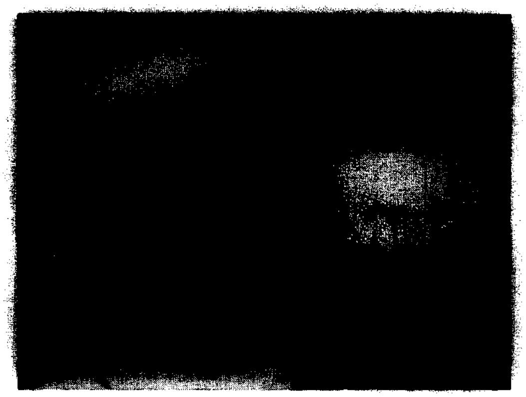


Fig. 2.—An aluminum cage is attached to the head by a metal and plaster skull cap. Records are made in three planes by a stylus that is attached to the lower incisors. The stylus writes as the chewing proceeds.

The frontal, the sagittal, and the horizontal planes of motion were registered. Reference markings were necessary to orient the tracings correctly. A fairly large sampling of patients with normal and abnormal occlusions should be selected for investigations of this type.

The idea of Christianson* was used to observe mastication from outside of the mouth. Casts of the dental arches of the subject were attached to the upper and lower teeth by means of plastic labial and buccal appliances. The casts were positioned outside of the mouth alongside the natural teeth and attached to the teeth by tubes of strong, light, rigid stainless steel (Fig. 3). When the subject chewed, the motions were seen on the casts and photographed outside of the mouth.

The best apparatus was one which was attached outside the mouth with nothing within the oral cavity to interfere with chewing. A chin cap was made of plastic

*Peter Christianson: Personal communication, May, 1958.

Fig. 3. Fig. 4.

Fig. 3.—Plastic casts of the subject's teeth are attached outside the mouth by metal rods. Chewing movements are observed and photographed.

Fig. 4.—A plastic chin cap with a small electric light is attached by rubber cement. The chewing movements are recorded by cinephotography. Mirrors on the metal frame attached to the headrest make it possible to record three planes of movement simultaneously.

with a light or stylus attached (Fig. 4). The subject could chew naturally with the apparatus in place. The error introduced by this arrangement is the muscular movement about the chin that is independent of the masticatory strokes. Also, the distance of the stylus from the natural teeth necessitates a corrective factor for the interpretation of the exact shape of the movement figure scribed by the stylus outside the mouth as compared to that inside the mouth.

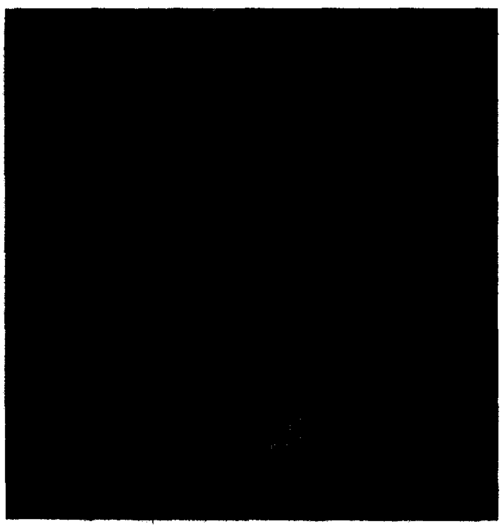
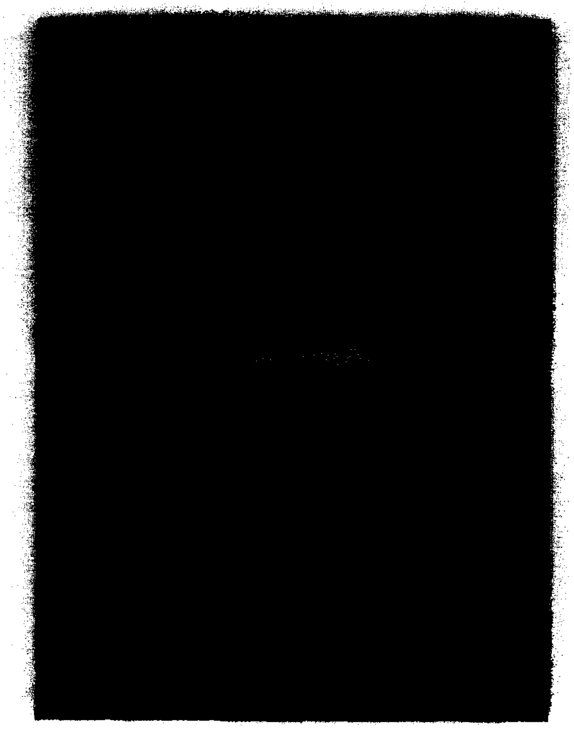


Fig. 5.—The camera is attached to a large, rigid tripod above the patient. A grid is attached as shown on the right side. The grid makes it possible to have a ruled grid appear in motion pictures of the chewing cycles. The horizontal plane is being photographed with the subject in a normal sitting posture.

A.



B.

Fig. 6.—The metal frame seen in Fig. 4 is attached to the headrest of the dental chair. The photographs are made in a dark room, using the stylus and tiny electric light attached to mandibular incisors (Figs. 1 and 4). Frontal, horizontal, and sagittal planes are photographed simultaneously by means of mirrors.

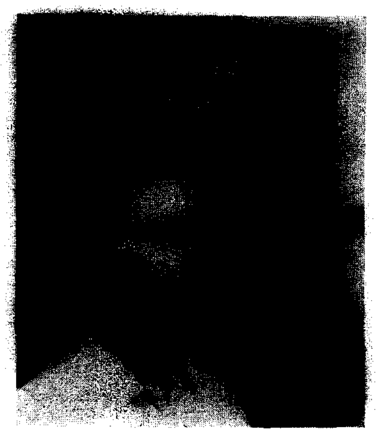


Fig. 7.—The subject's head is in a cephalostat. This method may inject inaccuracies in recording chewing movements. The eyeglass grid and rod stylus are used as the recording devices. The stylus is attached to the mandibular incisors.

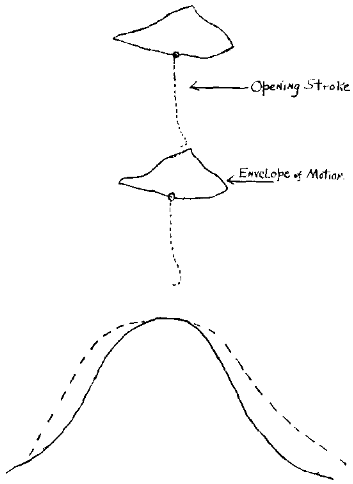


Fig. 8.

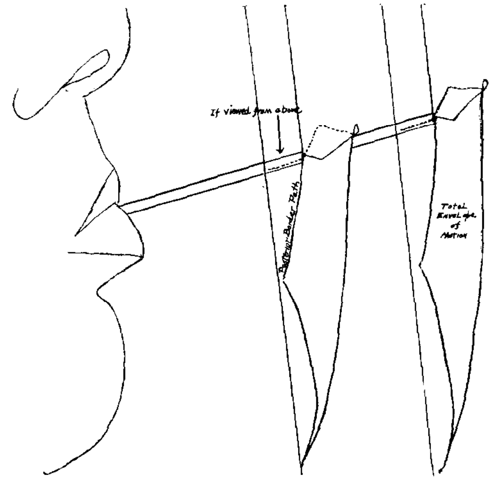
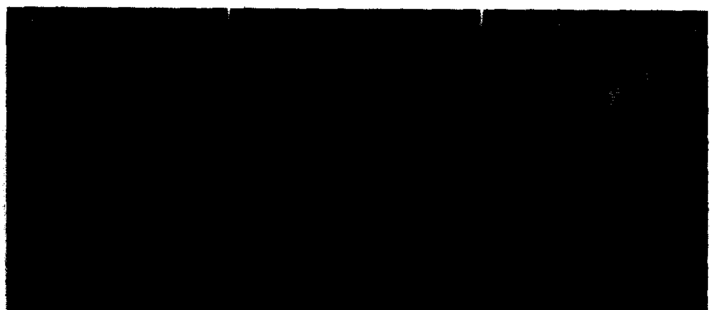


Fig. 9.

Fig. 8.—The subject makes one opening stroke. In this horizontal plane as viewed from above, the opening stroke appears to be behind the envelope of motion.

Fig. 9.—The dotted line behind the total envelope of motion in the sagittal plane represents how the posterior borderline appears when viewed from above in a horizontal projection (see Fig. 8).

Fig. 10.



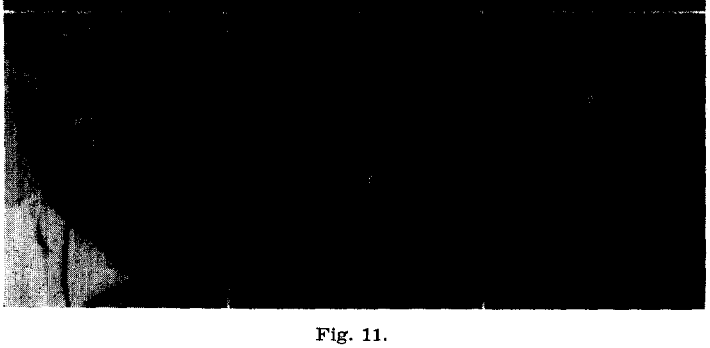


Fig. 11.

Fig. 10.—Three total envelopes of motion are made in the different planes.

Fig. 11.—The markings within the total envelopes represent the functional chewing strokes.

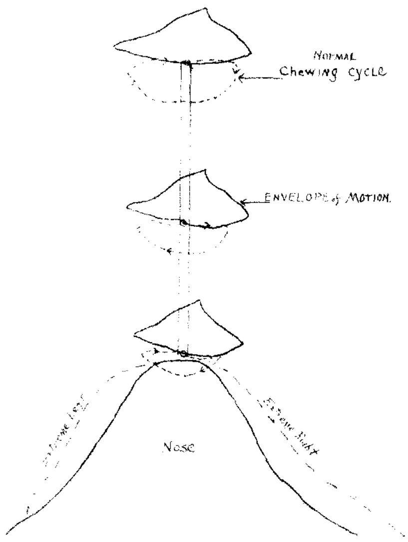


Fig. 12.

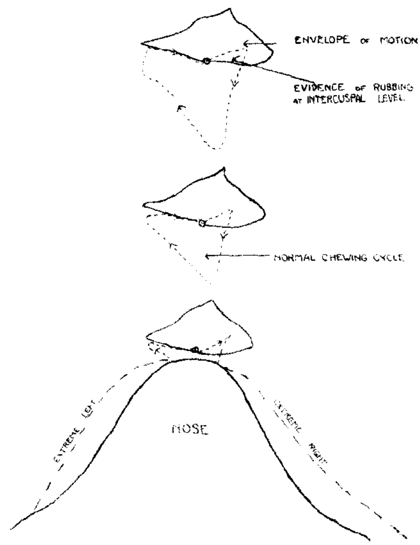


Fig. 13.

Fig. 12.—The subject is chewing a hard crust of bread. The chewing cycle appears to be behind the total envelope of motion in this horizontal projection. The entire chewing cycle took 1 3/16 seconds.

Fig. 13.—The subject is chewing a hard crust of bread and is observed from the horizontal plane. At the right side of the envelope of motion, a part of the chewing cycle appears within the envelope of movement. The total time of the cycle was 1 10/16 seconds.

REFERENCE LINES

Reference lines or points had to be established to relate movement in space to its surroundings and make it measurable. Diagrams of successive masticatory strokes could then be superimposed, and important data such as the size, speed, and time of the masticatory cycles could be obtained.

The first practical device consisted of a grid with ruled lines that was placed directly in the camera (Fig. 5). By this method, the finished motion picture had reference lines that were superimposed on the chewing strokes. The second reference grid was made of plastic and was suspended on a pair of eyeglasses (see Fig. 7). This grid could be moved in all three planes. The error introduced by movement of the eyeglasses had to be taken into consideration.

The movement of the head during mastication, including incision, chewing, and swallowing, was another unavoidable error. The head moves back in normal opening of the mouth and upward and backward during swallowing. Obstruction of these movements interferes with normal function. Both the lower and upper lips and the tip of the nose move during mastication. Therefore, these regions cannot be used as an accurate reference. It is almost impossible to use any part of the head for reference.

Motion in all three planes can be recorded simultaneously on motion picture film by the use of mirrors. However, recording in one plane at a time was found to be more accurate. The figures in the three planes are small, and the view of the indicator can be distorted (Fig. 6). The distance of each plane from the indicator and the angle of the mirror cause distortion and a difference in the size of the separate images.

The cephalostat has also been used in making these recordings. However, the result is artificial when the head is so forcibly stabilized. The ear plugs, which are also used for stability, increase the self-consciousness of the subject and definitely interfere with chewing and mandibular movements (Fig. 7). Also, the cephalometric chair does not give the subject sufficient support during the relatively long chewing procedure.

FINDINGS

The tests indicated that no chewing strokes could be made outside the boundaries of a three dimensional figure of the total envelope of motion. Many masticating strokes *seemed* to be behind the apex of the figure when the horizontal plane was viewed from above (Figs. 8 and 12). However, this deception was recognized immediately when a sagittal view was included in the study (Figs. 9 and 14).

In geometry, an envelope "is a curve or surface which is tangent to a continuous series of curves or surfaces."[1] It was relatively easy for the subjects to make a total envelope of motion in any or all of the three planes of function, namely, the

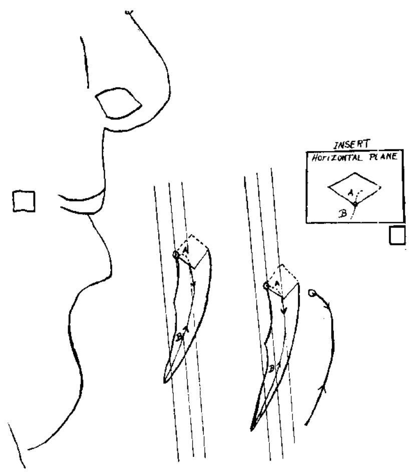


Fig. 14.

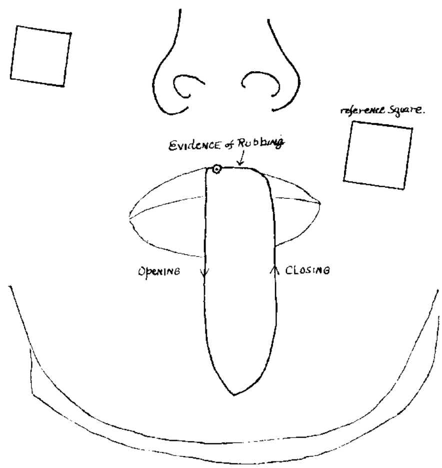


Fig. 15.

Fig. 14.—A tracing made of Fig. 28 demonstrates the crossing over of fields of function and "nonfunction." In functional movements, the mandible in the horizontal projection sometimes moves forward at the level of intercuspation into the diamond-shaped envelope of motion. An envelope of motion was drawn around the chewing strokes seen in Fig. 28. Parallel lines were made to project the chewing stroke into the horizontal plane. In the inset, *B* appears behind the wings of the seagull-shaped tracing, while *A* appears farther forward and within the diamond-shaped area. Although this envelope of motion is not accurate, it nevertheless clearly demonstrates the truth of what is shown in the main diagram.

Fig. 15.—The subject is chewing a hard crust of bread and is viewed from the frontal plane. There is evidence of rubbing at the interocclusal level. The opening time is 6/16 second. The closing time is 4/16 second. The horizontal part of the cycle required 7/16 second.

Fig. 16.

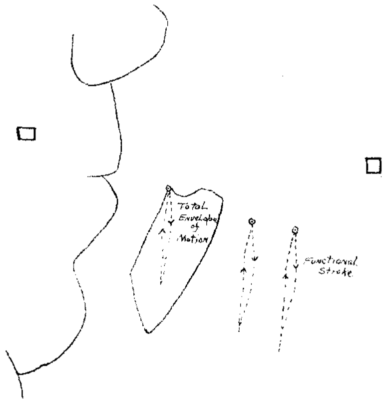


Fig. 17.

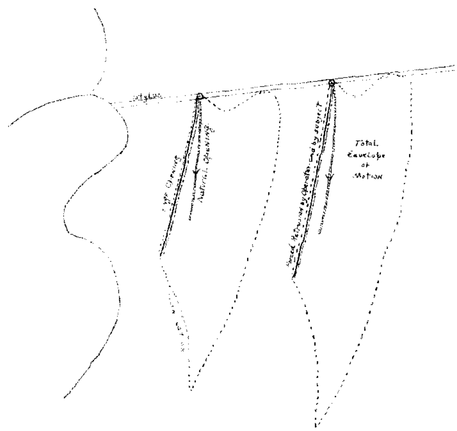


Fig. 18.

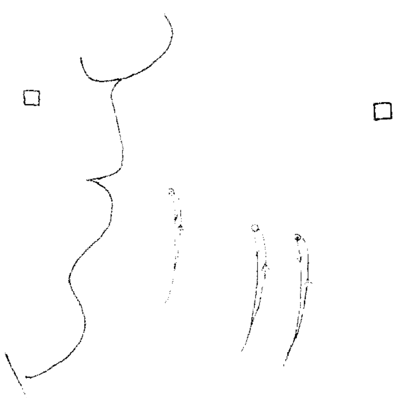


Fig. 16.—A natural opening and closing stroke. When viewed sagittally, the natural opening stroke is anterior to the closing stroke and terminates in a point with the mouth empty.

Fig. 17.—Forced retrusion by the dentist or the subject occurs along the same path. However, the natural opening stroke with the mouth empty occurs anteriorly to the posterior border path.

Fig. 18.—The first natural chewing cycle. The subject is chewing a crust of bread. The opening stroke is posterior to the closing stroke. The times required are 10/16 second for opening and 8/16 second for closing.

sagittal, the horizontal, and the frontal (Fig. 10). The boundaries of these complete envelopes of motion are border movements and are controlled mainly by nerves, bones, and ligaments. Posselt[2] has shown that a person under general anesthesia is capable of making the same total envelope of motion as he can without it. Aprile and Saizar[3] showed that a total envelope of motion can be made by moving a cadaver mandible after the muscles have been completely severed.

An entirely different envelope of motion was used by the same subjects during natural, functional chewing. The functional envelope of motion was much smaller and well within the borders of the total envelope of motion (Fig. 11). The natural, functional envelope is controlled reflexively, mainly by nerves and muscles.

LATERAL MOVEMENTS

Some dentists believe that lateral movements are completely outside the functional range of motion and that they play no part in occlusion. Although my findings demonstrate that the mandible drops behind the most retruded position when the subject opens the mouth. I cannot entirely agree with the statement that "as he engages in functional closure the mandible moved forward to (but not beyond) that position"[4] (Fig. 12). Some of the records demonstrated that the fields of function and lateral movements (rubbing movements) were not completely divided either before the level of intercuspation was reached or even after it was reached (Figs. 13, 14, and 40). There was evidence of some rubbing together of the teeth during the final phase of natural function (Figs. 15, 22, 25, 28, 32, and 33). The wide range of movement in the horizontal plane (one of the principal movements of articulators) occurred much less frequently than movements over a smaller range (Figs. 20, 22, 24, 25, 27, 28, 33, 34, and 36).

Lateral rubbing movements were also evident from observations of the casts functioning outside of the mouth, both as the food was reduced and in what has been called "the terminal functional orbit."* These movements appeared to be shearing movements. Sometimes they appeared long before the position of intercuspation was reached. Jankelson[5] suggested that these lateral movements of various ranges may result as ". . . a natural phenomenon of the shift in direction as the opening component of the chewing cycle is approached . . . ." Although no two of these lateral strokes were alike, when the models reached the range of intercuspation, there was evidence of a certain amount of cuspal guidance. The direction of the natural lateral movements was generally medial, while the direction of the movements of an articulator is usually radial.

The angle of approach as the mandible closed in natural, functional chewing often assumed peculiar individual characteristics. Closure took place on a curved line, a straight line, or a combination of both (Figs. 20, 21, 28, 34, and 36).

The path of closure to the position of intercuspation for adults with malocclusion and healthy oral structures is reflex in nature and is attained without cuspal clashing. Therefore, the closure in involuntary chewing seems to be a result of muscular coordination and nerve control. Thus, what appears as cuspal guidance may be nothing more than involuntary neuromuscular coordination in closing.

*Theodore Messerman: Personal communication, March, 1959.

The roll of the head and neck musculature in mastication has been impossible to determine because of the inaccuracies of recording the movements of the head. The head plays an important role in tearing, pulling, and generally assisting with mastication when eating sandwiches, raw fruit, or meat on bones. But this research was concerned only with average size boluses of food, which are generally chewed unilaterally on the preferred side. Large boluses often require bilateral mastication. This still must be investigated.

MOVEMENTS IN THE SAGITTAL PLANE

The opening movement of the mandible in the sagittal plane was usually anterior to the closing stroke, and at maximum opening, the movement of the recording stylus usually terminated in a point when the mouth was empty (Fig. 16). The start and finish as well as the length of the movements were the same in either forced retrusion or the normal maximal opening stroke with the mouth empty.

It was impossible to retrude the mandible forcefully and attain its maximum opening. However, as soon as translation of the condyles occurred and the condyles left the mandibular fossae, maximum opening was achieved.

The closing stroke was in two parts when the extreme envelope of movement was made with the mouth empty (Figs. 17 and 26). The lower part of the envelope of motion represents rotation *and* translation about moving transverse axes. The

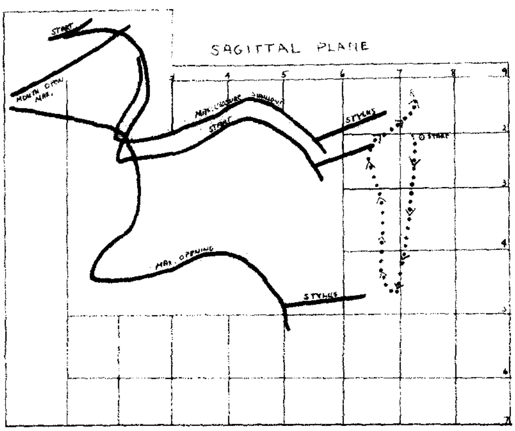


Fig. 19.—The subject is chewing a carrot. The opening stroke is anterior to the closing stroke on the twenty-ninth chewing cycle. The times are 3/16 second at the start, 4/16 second to open, and 8/16 second to close.

upper part of the envelope of motion represents rotation about the transverse axes which lie in or very close to the condyles. This part represents hinge closure.

With the mouth empty, forced retrusions by either the subject or the dentist occurred along the posterior border path and were identical. The natural opening stroke was further anteriorly than the closing stroke with the mouth empty (Fig. 16).

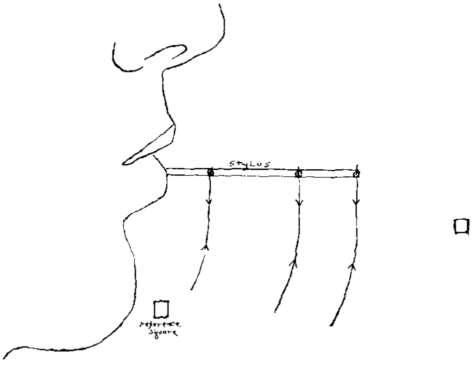


Fig. 20.

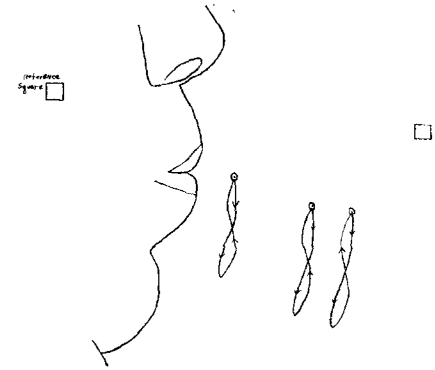


Fig. 21.

Fig. 20.—The subject is chewing a hard crust of bread. Opening and closing occur along the same path on the seventeenth cycle. The times are 7/16 second to open and 6/16 second to close.

Fig. 21.—The subject is chewing a hard crust of bread. The opening and closing strokes cross each other at the halfway mark. The times are 4/16 second for opening and 9/16 second for closing.

The opening stroke when chewing food was usually posterior to the closing stroke at the start (Fig. 18). However, as the chewing progressed, the opening stroke was sometimes anterior (Fig. 19), posterior, along the identical path (Fig. 20), or even crossed over from the closing stroke (Fig. 21). The chewing cycles in the sagittal plane with food in the mouth usually occupied a small area of the extreme envelope of movement.

The length of the functional opening stroke was usually not more than one-half to three-fourths that of maximal opening. The end of the natural opening cycle when chewing food was either pointed (Fig. 25), flat (Fig. 26), curved (Fig. 21), or a combination of these. The rubbing movements with the teeth in contact project out from the top and anterior part of the diagram (Figs. 22 and 28).

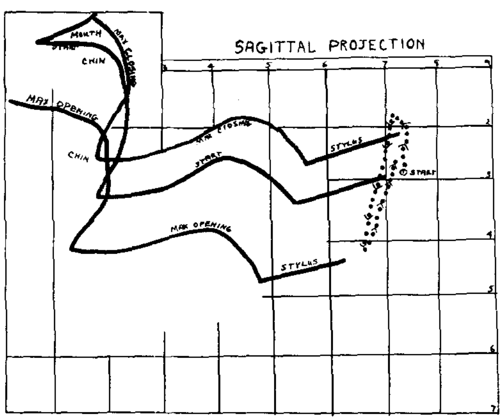
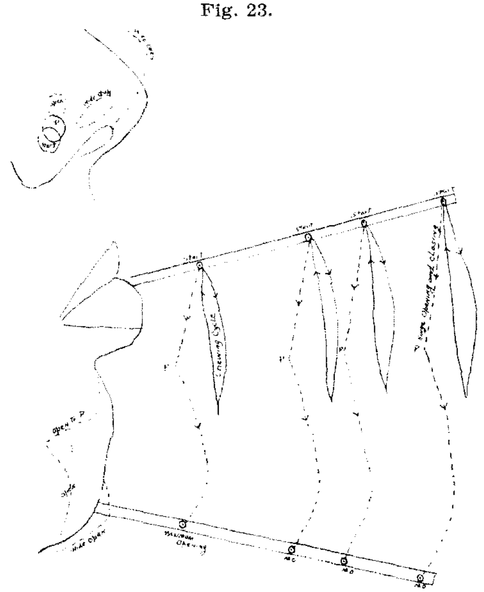


Fig. 22.—The subject is chewing a carrot on the seventh cycle. There is evidence of anteroposterior rubbing at or close to the level of intercuspation. The times are 8/16 second from the start upward, 5/16 second for opening, and 3/16 second for closing.

The posterior borderline or hinge closure which represents rotation about the transverse axis in the condyles did not seem to be reached in functional chewing when viewed in the sagittal plane (Fig. 23). The angle and length of the closing stroke were determined by the type of food, the vertical overlap of the anterior teeth, and the neuromuscular control. The closing stroke did not show this angular line in some vertical chewing strokes (Fig. 25).

Fig. 23.



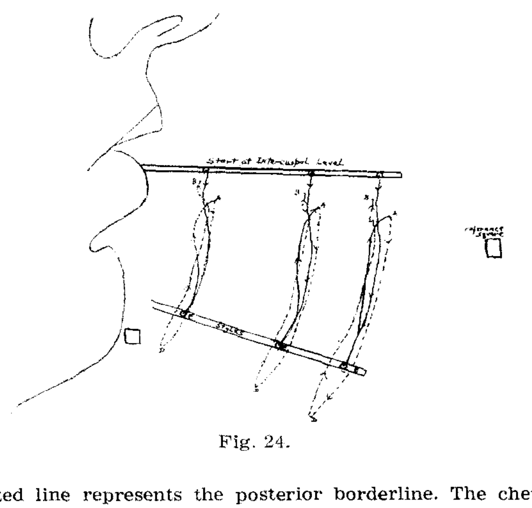


Fig. 24.

Fig. 23.—The dotted line represents the posterior borderline. The chewing cycle does not reach the posterior border or line of hinge closure. The time required is 7/16 second for opening and 6/16 second for closing.

Fig. 24.—The first chewing cycle requires 12/16 second for opening to E and 8/16 second for closing to A, which is below the level of intercuspation. The second chewing cycle starts at A, opening to D, and closing to B, which is still not at the level of intercuspation.

The beginning of the chewing cycle was below the level of intercuspation when chewing started from the rest position. The individual chewing cycles got smaller and smaller when tough food was broken up and mixed with saliva. At intervals, the tongue, lips, and cheeks gathered the food in small heaps and loaded it upon the occlusal platform. In these instances, the opening stroke was once again large, then got smaller as chewing continued. Often, the individual chewing strokes ended below the level of intercuspation, indicating that some food remained between the teeth (Fig. 24). Finally, the stylus went above the level of intercuspation as deglutition occurred, indicating that the subject's head was thrown back in deglutition.

A great deal of variation existed between the cycles. Some variation was caused by loading of the food by the tongue on the occlusal surface of the teeth. The closing part of the cycle shears and compresses the food and, therefore, is more effective than the opening stroke.

Often, the mandible remained in the area of the start of the masticatory stroke for from 1/5 to 1/3 second before the opening stroke occurred. This pause may be for resting or for applying pressure at the level of intercuspation, or both. The pause occurred too frequently to be accidental.

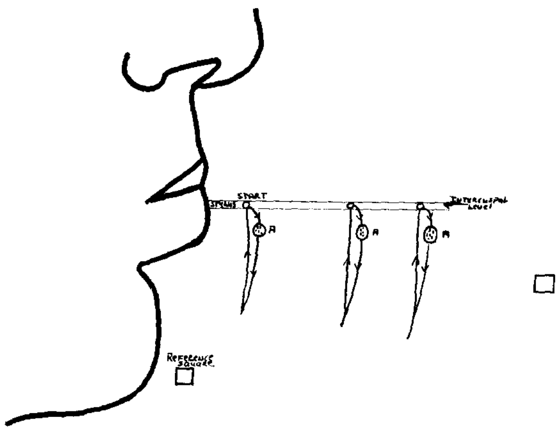
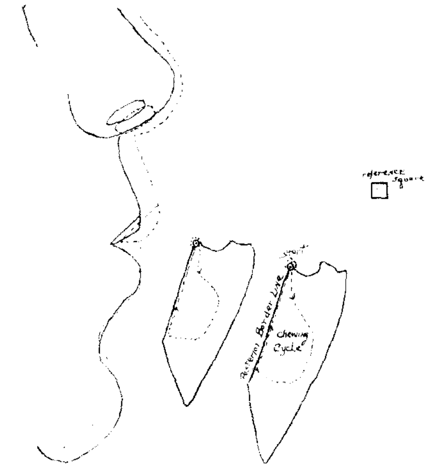


Fig. 25.—The subject is chewing a hard crust of bread. There is evidence of rubbing of the teeth posteroanteriorly at the start in the opening stroke. The closing stroke was straight upward to the level of intercuspation. The times required are 5/16 second to open to *A*, a 6/16 second pause in the area of *A*, 3/16 second to complete the opening, 5/16 second to close to the starting position, and a 5/16 second pause in the area of the starting position.

There were times during both the opening and closing stroke when the mandible stayed in one area for ½ to even 1 second (Fig. 25). The tongue may have been searching the buccal vestibules for some trapped food, or a large bolus may have been difficult to break down. The average single opening or closing cycle with such foods as carrots, bananas, or even meat took from 1/5 to 1/2 second.

In the final phase of chewing, the condyles are braced against the lower posterior border of the articular eminence while the mandible reaches its level of intercuspation.

Fig. 26.



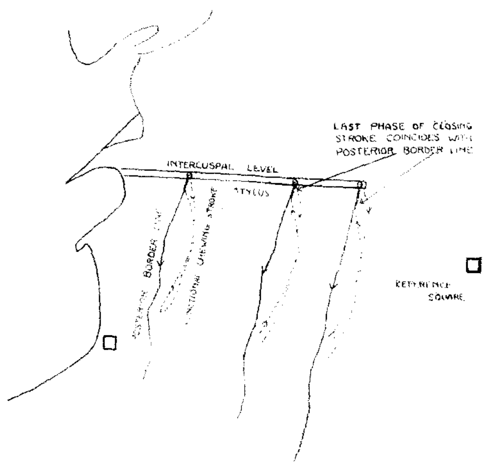


Fig. 27.

Fig. 26.—The total envelope of motion is superimposed on the chewing cycle. The subject is chewing hard candied orange peel. The closing stroke appears to be on the posterior border path. The facial contours are not identical, but the stylus marks are superimposed correctly.

Fig. 27.—The chewing cycle is superimposed on the posterior borderline or the line of farthest retrusion of the mandible. The last part of the closing stroke coincides with the posterior border or hinge line. The subject is chewing a hard crust of bread.

It has been suggested that these photographs were made from the side of the nonworking condyle (which was in translation) rather than the working condyle in its hinge-anchored position and that intercuspal interference may have caused the mandible to be pulled forward in swallowing.* In power closure, both condyles should be in the hinge position when the mandible reaches the level of intercuspa-

*C. A. Brekke: Personal communications, March and December, 1958.

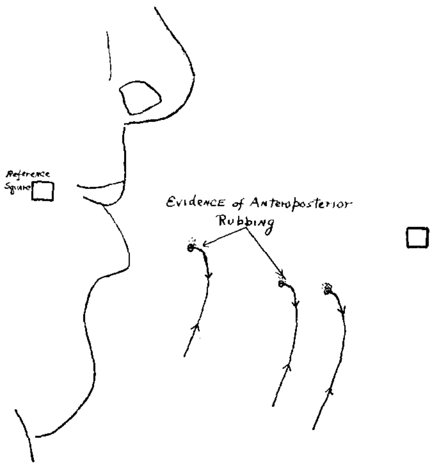


Fig. 28.—The subject is chewing a hard candied orange peel. The closing and opening paths coincide. This is evidence of anteroposterior rubbing of the teeth at the level of intercuspation. The times are 6/16 second in the area of the start, 9/16 second for opening, and 7/16 second for closing.

tion. While the belief in some theories of occlusion is that the mandible follows the posterior border path during power chewing, only infrequently did this occur (Figs. 26 and 27).

Some investigators[6,7] maintain that anteroposterior movements take place in the sagittal plane only when the anterior teeth are used for the prehensile act and that the rubbing movements of the posterior teeth are only laterally and transversely directed when the posterior teeth are in function. However, distinct anteroposterior rubbing movements were observed while watching the casts of a subject chewing natural food. The casts were outside the mouth and attached to the subject's teeth. Some of the sagittal diagrams also confirm these movements, and they were of such magnitude that a misinterpretation of right or left lateral movements on a sagittal projection was impossible (Figs. 22, 25, and 28).

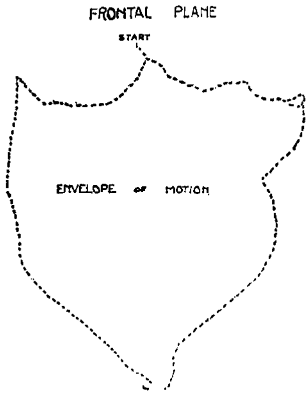
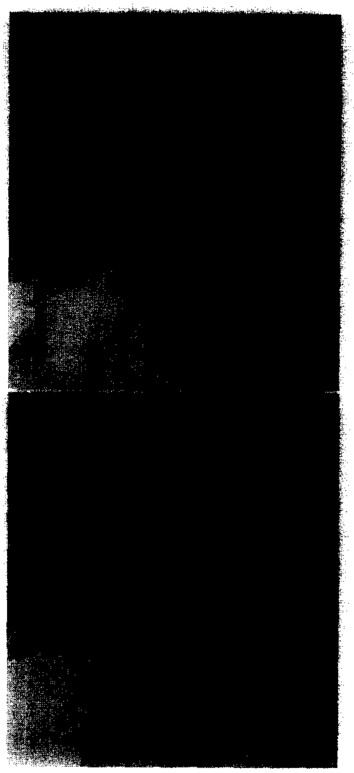


Fig. 29.—The total envelope of motion in the frontal plane.

Fig. 30.—Several functional chewing strokes are included within the total envelope of motion. The subject is chewing a raw carrot. The opening stroke is straight down. The loading is horizontally directed, followed by the closing strokes, which are all on the right side.

A.



B.

Fig. 31.—*A*, The complete envelope of motion is followed by one opening and closing stroke with the mouth empty. *B*, The complete envelope of motion is followed by two functional strokes. The subject is chewing a raw carrot. The head moved slightly, otherwise the functional strokes would be within the total envelope of motion. The strokes in this instance are teardrop in shape.

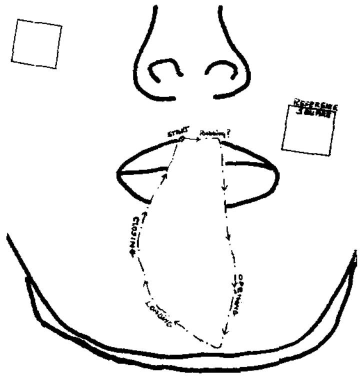


Fig. 32.

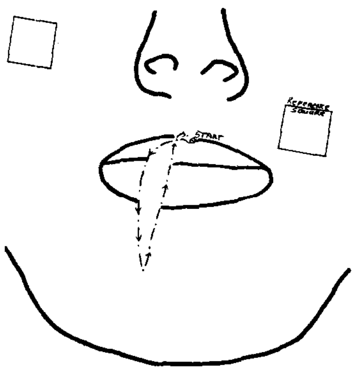


Fig. 33.

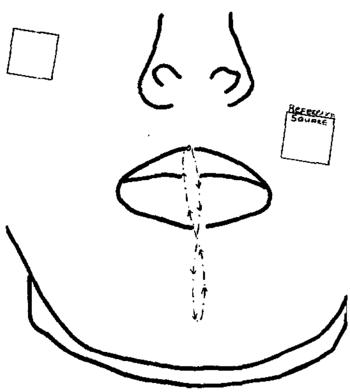


Fig. 34.

Fig. 32.—The subject is chewing a hard crust of bread. There is evidence of rubbing of the teeth at the level of intercuspation during the wide chewing stroke. The times are 4/16 second from the start to the left position, 5/16 second for opening, and a 6/16 second pause in the area of starting.

Fig. 33.—The subject is chewing a hard crust of bread. Note the angulation at the end of the closing stroke. The times are a 4/16 second pause in the area of start, 5/16 second for opening, 3/16 second for closing, and 2/16 second from the top of closing to the starting position.

Fig. 34.—The subject is chewing a hard crust of bread. The opening and closing strokes cross each other about midway in the cycle. The closing stroke is straight upward. The times are an 8/16 second pause in the area of start, 4/16 second for opening, and 4/16 second for closing.

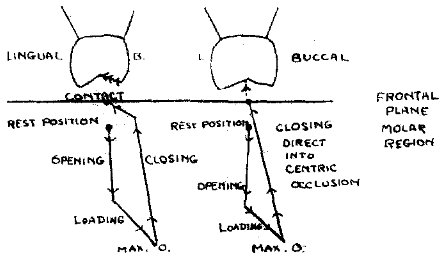
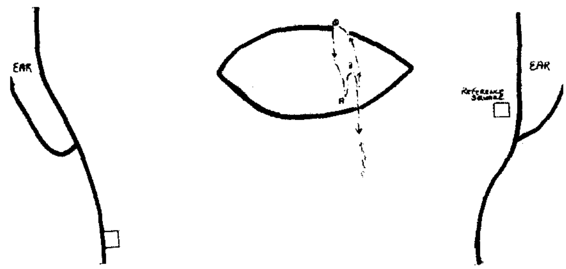


Fig. 35.—The closing stroke in the molar region when chewing soft food was often in a straight line. (From Wild, W.: Functional Prosthetics, Basel, 1950, Benno Schwabe & Co.)

MOVEMENTS IN THE FRONTAL PLANE

In the frontal plane, the extreme envelope of jaw movement with the mouth empty produced a seagull-shaped tracing. The lateral arms of the tracing spread widely to the right and to the left and came to a point at extreme opening (Fig. 29). Wings of the tracing are curved because of the convexities of the cusps. The length of the angulation at the top of the side arms differed with the ability of the subject to make right and left lateral movements. The shape of the total tracing

Fig. 36.



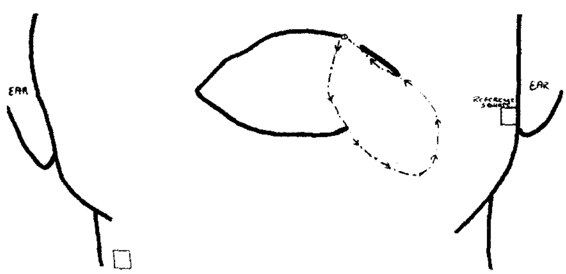


Fig. 37.

Fig. 36.—The subject is chewing a hard crust of bread. From the level of intercuspation, the opening stroke ends at *A*, closes to *B* (which is below the level of intercuspation), then opens again to *C*, and closes to the level of intercuspation. The times are 2/16 second at the start, 7/16 second to open to *A*, 4/16 second to close to *B*, 4/16 second to open from *B* to *C*, and finally 7/16 second to close to the starting position.

Fig. 37.—The subject is chewing a hard crust of bread. The closing stroke is medially directed, which is quite common in reflex functional chewing. The times are 3/16 second at the start, 6/16 second for opening, and 9/16 second for closing.

was similar to that of a shield. These movements depend on the nerves and ligaments, the degree of incisal overlap, the cusp height of the posterior teeth, and to some extent the musculature.

The natural functional envelope during chewing was much smaller and well contained within the extreme envelope (Fig. 30). The opening stroke with the mouth empty was more or less vertical and was usually more rapid than the closing stroke (Fig. 31). In functional chewing, the closing stroke occurred most often from the side on which the chewing was performed. The wide part of the cycle from the end of the opening to the start of the closing stroke is said to represent

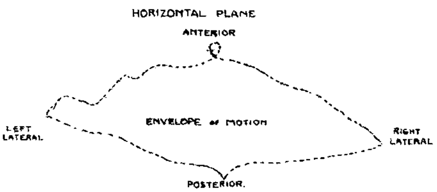


Fig. 38.—The complete envelope of motion in the horizontal plane.

the loading of the food on the occlusal surfaces of the teeth. However, it also may represent a movement of the mandible into a more effective working position, depending on the type and size of the bolus (Fig. 32).

The chewing diagram was occasionally teardrop in form (Fig. 31). Chewing often took place on one side only. As the bolus was reduced, the strokes became smaller and smaller until swallowing occurred. Sometimes, the tongue gathered the food in a small heap, and then the masticatory stroke was large.

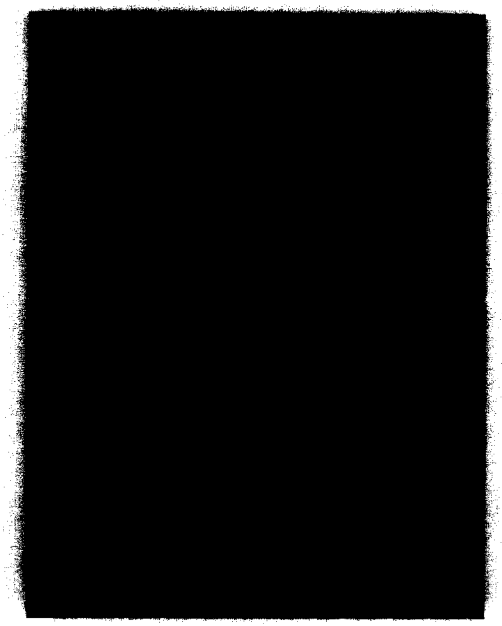
During the final crushing of the food and swallowing, the indicator was located in a small area in the neighborhood of centric occlusion but did not remain at one point. During this time the debatable rubbing and crushing between tooth cusps occurred in the terminal functional orbit until final swallowing (Fig. 32). Once again, the final part of the closing line was often angulated (Fig. 33).

The degree of angulation and the size of the final closing line depend upon the angulation of the buccal and lingual cusps of the upper and lower posterior teeth as they intercuspate in lateral movements in the terminal functional orbit. Neuromuscular coordination may also be a factor. The masticatory strokes in the frontal plane, which are predominantly vertical, do not have this angulated terminal end of the closing stroke (Fig. 34).

The neuromuscular system may be responsible, in part, for the steepness of the angle of closure during mastication. The form of the diagram in the frontal plane depends upon the toughness of the food and the areas of posterior tooth contact. With fibrous food which is difficult to chew, the closure may be erratic until the lower teeth reach the upper buccal working surfaces. Then the lower cusps slide into centric occlusion. This is the phase of rubbing which is in a transverse or lateral direction toward the midsagittal plane. With soft food, the closing stroke was often directly in a straight line from the side of chewing into centric occlusion at the level of intercuspation (Fig. 35). Once again, mastication may start below the level of intercuspation at rest position. However, the teeth did not always reach the level of intercuspation, as with hard foods during the reducing period (Fig. 36). Here again, the masticatory strokes were similar but not duplicates of each other. Sometimes, the paths were crossed over from right to left when the tongue placed the bolus on the opposite side (Fig. 34). Many of the movements were made from the lingual (medial position) to the buccal (lateral position) in voluntary chewing. Reflex functional chewing was generally directed medially (Figs. 32 and 37).

Deglutition occurred several times during the chewing of a bolus. Saliva was being constantly mixed with the food. The tongue, lips, and cheeks were always at work keeping the food on the occlusal surfaces of the teeth. The chewing was both

A.



B.

Fig. 39.—*A*, The intraoral tracer enables the dentist to change the vertical relation to three or more levels and make tracings at each level. *B*, Horizontal, frontal, and sagittal tracings are made with an intraoral tracer in position at three different levels of opening, including the level of intercuspation. First, rubbing movements of the teeth are made, then one opening and closing movement. The most important level is that of intercuspation.

cyclic and angular. In final swallowing, the head moved back, and a curved line was seen above the centric contact area in the diagram.

THE HORIZONTAL PLANE

In the horizontal plane, the extreme envelope of movement made with the teeth in contact looked somewhat like a diamond or two seagull-shaped tracings with their apices pointed opposite each other (Fig. 38). The opening stroke was somewhat like a straight or curved line projecting out from the apex of the most posterior seagull tracing. The opening movement curved toward the rear and, in this perspective, looked like a line behind the seagull tracing (Fig. 8). This line in a sagittal projection represents the posterior border path (Fig. 9).

The functional chewing envelope of movement may appear to one side and behind the seagull tracing or on both sides (Figs. 12 and 13). The envelope may cross over the posterior terminals of the seagull tracing and appear within the diamond-shaped area (Figs. 11 and 13), representing the rubbing and tearing of food in or near the terminal functional orbit. The envelope may also represent the translating condyle in any open position of the mandible.

In final swallowing, the indicator was sometimes found at the apex of the seagull tracing but more often slightly anterior to it. The subject's head moved back

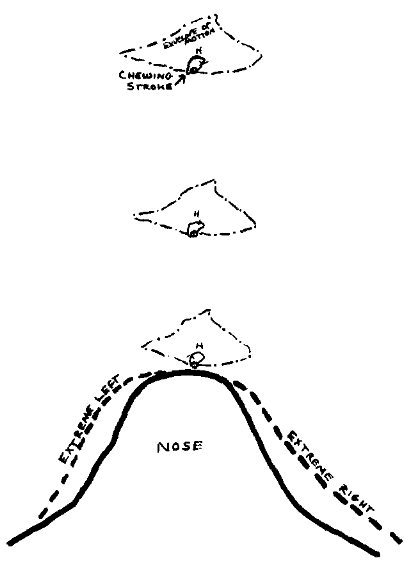


Fig. 40.—The subject is chewing a hard crust of bread. The chewing stroke appears to be within the envelope of motion in this projection.

at final swallowing, and once again a line above and anterior to the apex of the seagull tracing was seen in the diagram. The diamond formed by the extreme envelope of movement was narrow between the apices and wide laterally (Figs. 10 and 38).

The areas of function and nonfunction may be considered in the horizontal plane. While it is true that there is a definite centric relation for each level of vertical opening (Fig. 39), function and nonfunction can be described only at one specific level. This level is the level of intercuspation or the level at which all chewing terminates.*

*C. A. Brekke: Personal communications, March and December, 1958.

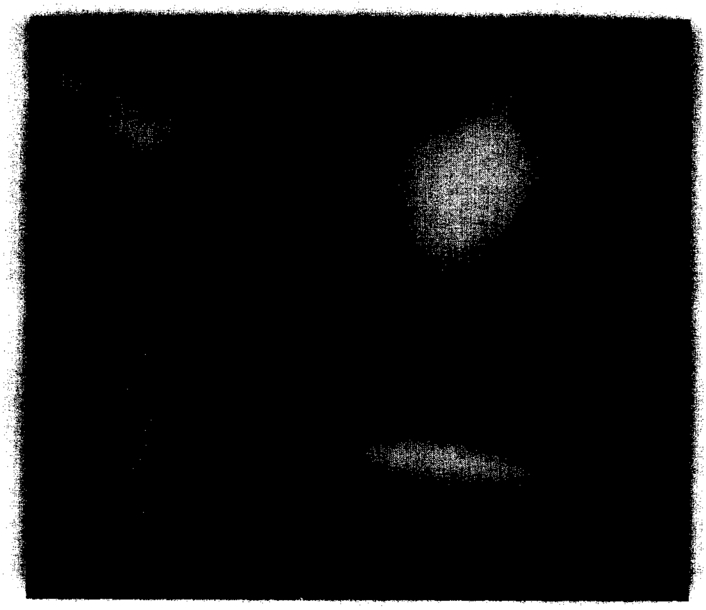


Fig. 41.—Models of the envelopes of motion. Both the total and functional envelopes of motion are shown for comparison of size and position.

Most functional chewing occurs in the sagittal plane. However, some functional chewing also takes place in the horizontal plane and at the level of intercuspation. Some subjects chew anteroposteriorly and posteroanteriorly from the retruded position of the mandible to a forward position within the confines of the seagull tracing, at or very close to the intercuspal level, in the horizontal plane (Figs. 14 and 40).

Even though I may have recorded the action of the translating condyle, which is the nonworking member, both condyles work even though one may work less effectively at any given moment. Many subjects chew on both sides simultaneously, especially when chewing large boluses of food.

The terminal chewing stroke is in the region of the apex of the seagull tracing. Chewing on the horizontal plane is usually done on the preferred side and generally in a buccolingual direction. The subject makes many eccentric movements which may be due to individual nerve impulses.

THE ENVELOPES OF MANDIBULAR MOVEMENT

I have made a model based on the diagrams from 1 subject used in this research to give a composite picture of the total envelope of motion and the functional envelope. It demonstrates the difference between these two envelopes (Fig. 41).

CONCLUSIONS

Our true capacity to advance in dental science depends upon the depth of our understanding of the fundamentals which underlie our knowledge of biologic and dental facts. In spite of the remarkable progress, our understanding of fundamentals is woefully inadequate. While we can perform near miracles in prosthodontics and even can improve upon the natural conditions, we are unable to answer many of the simplest questions raised from scientific observation in the dental sciences. An enormous reorientation of our scientific effort into long range, undirected basic research is needed to fill in the glaring gaps in our knowledge.

Research that is carried out with patience and persistence will bring new life to dentistry. By means of research, science is advanced, knowledge is increased, and humans win an even greater freedom from dental disease.

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