

SECTION VI

SIMULATED CHEWING MOVEMENTS

IN DENTULOUS AND EDENTULOUS SUBJECTS

SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS
AND EDENTULOUS SUBJECTS

SIMULATED CHEWING MOVEMENTS:

METHOD:

The simulated masticatory movements were recorded by asking the subject to bring the teeth together into the intercuspal position and then to pretend to be chewing food. At the end of the sequence, the subject was asked to again bring his teeth together and stop. The entire sequence was recorded on the mandibulograph at a paper speed of 25 mm/sec.

Three variations of the simulated chewing movements were recorded for each subject:

1. Simulated Chewing ad lib.

The subject performed chewing movements on the side of his choice and in the manner of his preference without any instructions or restrictions.

2 & 3 Simulated Chewing on the Right and Left Sides:

The subject was instructed to simulate chewing of food on a prescribed side of the mouth in turn. In the following text, the prescribed side has been referred to as the "Ipsilateral" side and the other side as the "contra-lateral" side.

In one dentulous and four edentulous subjects, a total of 61 cycles representing 13 cycles from the dentulous and twelve cycles from each of the four edentulous subjects were recorded on the mandibulograph.

For each cycle, the outline forms of frontal, sagittal, and

horizontal views of the movement were developed as described under the section on mandibulography.

A detailed examination of the following was then carried out:

1. Positional relationship of the opening and closing strokes.
2. The part played by the cuspal guidance in the simulated movements.
3. Envelope of movement space used during simulated chewing movements compared to the total envelope of motion.

1. POSITIONAL RELATIONSHIP OF THE OPENING AND CLOSING STROKES:

Observations were made in the frontal, sagittal and horizontal views, and the following features were noted:

(a) The Points of Initiation of Individual Cycles in Relation to the Intercuspal Position:

There could be eight possibilities in respect to the point of initiation of the opening strokes:

- (i) From closed-mouth position: When the movement initiated from the zero point or any other position located at that level.
- (ii) From open-mouth position: When the point of initiation was located some distance below the level of zero point.

In the Frontal View:

- (iii) On the right side of the Central Vertical Axis (C.V.A.) from closed or open-mouth Positions.
- (iv) On the C.V.A. in closed or open-mouth positions

- (v) On the left side of the C.V.A. from closed or open-mouth positions.

In the Sagittal View:

- (vi) Anterior to the C.V.A. from closed or open mouth positions.
- (vii) On the C.V.A. in closed or open-mouth position.
- (viii) Posterior to the C.V.A. from closed or open-mouth positions.

(In the frontal view, the Z axis when viewed from its anterior end appeared as a point, and all positions of the "jaw point" located directly on the Z axis anteroposteriorly appeared to overlap one another, showing up as a single point regardless of whether the positions were located anterior to, on, or posterior to the intercuspal position. Similarly, the sagittal view alone gave no indication of the exact position of the "jaw point" on the Y axis. The exact points of initiation and termination of the movement cycles in relation to the intercuspal position could be determined by verifying these positions in at least two of the three views of the movement cycle).

(b) The Side of Initiation of the Opening Stroke in Relation to the Central Vertical Axis (C.V.A.):

The path followed by the initial 5.0 mm. of the opening stroke was considered indicative of the side of initiation of the opening stroke. There were six possibilities:

Frontal View:

- (i) On the right side of the C.V.A.
- (ii) Along the C.V.A.

(iii) On the left side of the C.V.A.

Sagittal View:

(iv) On the anterior aspect of the C.V.A.

(v) Along the C.V.A.

(vi) On the posterior aspect of the C.V.A.

(c) The Location of the Maximal Opening and Point of Initiation of the Closing Stroke in Relation to the C.V.A.:

Similar to above (b), there were six possibilities

Frontal View:

(i) On the right side of the C.V.A.

(ii) On the C.V.A.

(iii) On the left side of the C.V.A.

Sagittal View:

(iv) Anterior to the C.V.A.

(v) On the C.V.A.

(vi) Posterior to the C.V.A.

(d) Form of Maximally Open Position:

There could be two possibilities:

(i) "Point" Form: The opening stroke terminated in a point position and the jaw, without any loss of time, reversed its direction of motion initiating the closing stroke. There would be no lateral or anteroposterior shifting of the jaw at this point.

(ii) "Loop" Form: At the termination of the opening stroke, the jaw point executed a "Loop" in a lateral or anteroposterior direction to change into the closing stroke.

The two variations were looked for in the frontal and sagittal views.

(e) Path of Closing Stroke in Relation to the C.V.A.:

The path followed by the terminal 5.0 mm. of the closing stroke was considered indicative of its relationship to the C.V.A. There were six possibilities:

Frontal View:

- (i) The closing stroke could pass on the right side of the C.V.A.
- (ii) The closing stroke could pass along the C.V.A.
- (iii) The closing stroke could pass on the left side of the C.V.A.

Sagittal View:

- (iv) The closing stroke could pass anterior to the C.V.A.
- (v) The closing stroke could pass along the C.V.A.
- (vi) The closing stroke could pass posterior to the C.V.A.

(f) The Mutual Positional Relations of the Opening and Closing Strokes to the C.V.A.:

The relationship of the opening and closing strokes to the C.V.A. was examined. There could be six possibilities:

Frontal View:

- (i) The opening stroke could be closer to the C.V.A. than the closing stroke.
- (ii) The closing stroke could be closer to the C.V.A. than the opening stroke.
- (iii) The opening stroke could coincide with the closing stroke.

Sagittal View:

- (iv) The closing stroke could pass anteriorly to the opening stroke.
- (v) The closing stroke could pass posteriorly to the opening stroke.
- (vi) The closing and opening strokes could coincide.

(g) Point of Termination of the Individual Cycles in Relation to the Intercuspal Position:

Similar to the point of initiation, there could be eight possibilities:

- (i) The closing stroke could terminate in a closed mouth position, on the zero point or other positions at the same level.
- (ii) The closing stroke could terminate in an open mouth position some distance below the zero point.

In the Frontal View:

- (iii) The closing stroke could terminate on the right side of the C.V.A.
- (iv) The closing stroke could terminate on the C.V.A. in closed or open mouth positions.
- (v) The closing stroke could terminate on the left side of the C.V.A.

In the Sagittal View:

- (vi) The point of termination of the closing stroke could be located anterior to the C.V.A.
- (vii) The closing strokes could terminate on the C.V.A.
- (viii) The closing stroke could terminate posterior to the C.V.A.

Horizontal View:

Observations in the horizontal view were made to verify and confirm those made in the frontal and sagittal views.

2. ROLE PLAYED BY CUSPAL GUIDANCE:

The maximal cuspal guidance angles for each subject were measured from the sliding contact excursions in the right, left and protrusive directions as described earlier and are shown in Table No. 12. Using these angles as guides, the angles formed by the tangents to the occlusal 0.5 mm. excursion of the opening and closing paths of movement during the simulated chewing were measured for each cycle. When these tangent angles were equal to, or less than the maximal cuspal guidance angle for the particular subject, the particular stroke was considered to be influenced by cuspal guidance. When these lesser tangent angles showed up in the frontal view of the cycle, these indicated contacts between the opposing cusps during lateral excursion. When the lesser tangent angles showed up in the sagittal view, these represented contacts during protrusive or retrusive excursions, depending upon the direction of motion.

When the tangent angles were greater than the maximal cuspal guidance angle, the opening or closing movements of the jaw point were considered as "Direct" or free from any cuspal guidance.

3. ENVELOPE OF MOVEMENT SPACE USED DURING SIMULATED CHEWING SEQUENCES:

The frontal, sagittal and horizontal views of the envelope of movement space used during any sequence were developed

by superimposing the respective outline forms of the individual cycles as described earlier.

The observations were made in respect to:

- (a) General shape and form of the envelope
- (b) Location of the intercuspal position in relation to the envelope
- (c) Disposition of the opening and closing strokes in the envelope.

SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS SUBJECT 'A'

The three simulated chewing exercises i.e., the ad lib. chewing, chewing on the right side, and chewing on the left side were examined separately and the findings correlated and summarized.

POSITIONAL RELATIONSHIP OF THE OPENING AND CLOSING STROKES:

1. Simulated ad lib. Chewing in the Dentulous Subject 'A'
(Fig. No. 36)

A total number of five cycles were examined.

Frontal View:

- (a) All the cycles initiated from zero position.
- (b) In all the cycles, the opening stroke initiated on the left side of the central vertical axis (C.V.A.)
- (c) In all the cycles, the maximal opening was reached on the left side.
- (d) (i) In four out of five cycles, the maximal opening was a point position. The jaw point came to a stop at maximal opening and without any loss of time, reversed direction to perform the closing

stroke, indicating that no lateral movement occurred at the point of maximal opening during these cycles.

- (ii) In the remaining cycle, the opening stroke formed a loop at the maximally open position to change into the closing stroke, the jaw point shifting medially at maximal opening. (Fig. No. 36, Cycle No. 4)
- (e) (i) In three out of five cycles, the closing stroke crossed over to the right side of the C.V.A.
(ii) In one cycle, the closing stroke remained on the left side throughout its course.
(iii) One closing stroke passed along the C.V.A. in the terminal 6.0 mm. of its course.
- (f) (i) In four out of five cycles, the closing strokes passed closer to the C.V.A. than the opening strokes.
(ii) In one cycle, the closing stroke passed farther away from the C.V.A. than the opening stroke for most of the course, but at the level of the occlusal fifth of the total opening 4.5 mm. from the intercuspal position, it crossed over to pass closer to the C.V.A.
- (g) All cycles terminated at closed mouth zero position.

Sagittal View:

- (a) All cycles initiated from the closed mouth zero position. When this is related to the position in the frontal view, it indicates that all ad lib. simulated chewing cycles initiated from the intercuspal position.
- (b) All the opening strokes initiated on the anterior aspect of the C.V.A.

- (c) (i) In two cycles, the opening strokes reached a maximally open position anterior to the C.V.A.
- (ii) In three cycles, the maximally open position was reached 0.5 mm. posterior to the C.V.A.
- (d) All maximal openings were point positions. This confirms the similar observation in the frontal view. Cycle No. 4 showed a loop formation in the frontal view, absence of loop formation in the sagittal view indicates absence of anteroposterior shifting at maximal opening.
- (e) (i) Two cycles were executed anterior to the C.V.A. through the entire course.
- (ii) In three cycles, 0.5 mm. to 1.0 mm. of the closing strokes at their initiation passed distal to the C.V.A. The closing strokes then crossed the C.V.A. and passed anteriorly to it for the rest of the course.
- (f) In three out of five cycles, the closing strokes passed anteriorly to the opening strokes but the anteroposterior distance between the opening and closing paths were never more than 0.9 mm.
- (g) All cycles terminated in the intercuspal position.

Horizontal View:

The horizontal view of the ad lib. simulated chewing movements confirms the observations in the frontal and sagittal views.

2. Simulated Chewing Movements on the Right and Left Sides in the Dentulous Subject 'A' (Figs. No. 37, 38)

Frontal View:

- (a) All the eight cycles initiated from closed mouth zero position.

- (b) The opening stroke initiated on the ipsilateral side in four cycles and on the contra lateral side in four cycles.
- (c)
 - (i) In four cycles, the maximal opening was reached on the ipsilateral side.
 - (ii) In three, the maximal opening was reached on the contralateral side.
 - (iii) In one, the maximally open position was located on the C.V.A.
 - (iv) In seven, the maximal opening was located on the same side as the initiation of the opening stroke.
- (d)
 - (i) In six of the cycles, the maximal opening was a point position.
 - (ii) In two, the jaw point formed a loop to change the opening stroke into closing stroke.
- (e)
 - (i) In six of the cycles, the closing stroke passed entirely or for most of its length on the ipsilateral side.
 - (ii) In two of the cycles, the closing stroke was located on the contralateral side, but reached the C.V.A. some distance before the zero point was reached.
- (f)
 - (i) In four of the cycles, the closing stroke passed closer to the C.V.A. than the opening stroke.
 - (ii) In three of the cycles, the opening stroke passed closer to the C.V.A. than the closing strokes.
 - (iii) In one of the cycles, the opening and closing strokes coincided with one another in the occlusal half of the course.
 - (iv) Abrupt midcourse changes in the direction of opening and closing paths of motion were seen in seven of the cycles. The changes in direction of motion were considered abrupt when the jaw point movement

course deviated from the initial direction more than 45 degrees for a distance of 2.0 mm.

These deviations occurred anywhere beyond 0.5 mm. distance from the zero point.

- (g) All the cycles terminated in zero position.

Sagittal View:

- (a) All cycles initiated from intercuspal position.
- (b) (i) Five of the opening strokes initiated on the anterior aspect of the C.V.A.
- (ii) One of the opening strokes passed along the C.V.A. for some distance before manifesting a protrusive tendency.
- (iii) Two of the opening strokes initiated on the distal aspect of the C.V.A.
- (c) (i) In five of the cycles, the maximally open position was reached anterior to the C.V.A.
- (ii) In three of the cycles, the maximally open position was located posterior to the C.V.A.
- (d) (i) Three of the opening strokes formed a postroanterior loop at maximally open position to change into a closing stroke.
- (ii) Five of the opening strokes reached maximal opening in a point position.
- (e) (i) In six of the cycles, the closing strokes passed anteriorly to the C.V.A.
- (ii) In two of the cycles, the closing strokes either passed posterior to the C.V.A., or along it.
- (f) (i) In four of the cycles, the closing stroke passed anteriorly to the opening stroke.
- (ii) Two of the closing strokes passed distally to the opening stroke for the entire length of the course.

- (iii) In one of the cycles the closing stroke passed posterior to the opening stroke for most of the length of the course, but in the terminal 2.5 mm. the closing stroke shifted anterior to the opening stroke.
- (iv) In one of the cycles, the closing stroke passed anterior to the opening stroke for most of the course, but near the terminal part, shifted distally to the opening stroke.
- (g) All the cycles terminated in the intercuspal position.

II. CUSPAL GUIDANCE CHARACTERISTICS IN DENTULOUS SUBJECT 'A'

Simulated ad lib. Chewing: (Fig. No. 36, Table No. 13)

1. One out of five cycles showed no cuspal guidance at all. The opening stroke formed an angle of 90° both in the frontal as well as the sagittal view during the initial 1 mm. vertical displacement. The closing stroke formed an angle of 90° to the Y axis in the frontal view during the terminal 3.0 mm. of the closing movement. In the sagittal view, the closing stroke formed an angle of 56° with the Z axis which is greater than the maximal cuspal guidance angle, measured for this subject.
(Fig. No. 36, Cycle No. 2)
2. The opening stroke in two cycles showed cuspal guidance in both frontal as well as sagittal view.
(Fig. No. 36, Cycles No. 1 and 4)
3. In one cycle, cuspal guidance occurred only in the frontal view of the opening stroke.
(Fig. No. 36, Cycle No. 3)
4. In one cycle, cuspal guidance was seen only in the sagittal view of the opening stroke.
(Fig. No. 36, Cycle No. 6)
5. Cuspal guidance was not evident in any closing stroke viewed frontally.
6. Viewed sagittally, only one cycle showed cuspal guidance in the closing stroke.
(Fig. No. 36, Cycle No. 3)
7. Cuspal guidance during the opening strokes was in a protrusive direction, while in the closing strokes, it occurred in a retrusive direction.

Simulated Chewing on the Right and Left Sides:

(Figs. No. 37, 38., Tables No. 14 and 15)

1. In all the cycles, cuspal guidance was seen to occur either in the opening or in the closing strokes in at least one view.
2. In only 12 percent opening strokes, cuspal guidance was indicated by both the frontal and sagittal views.
3. In 50 percent of the opening strokes, cuspal guidance was indicated in the frontal view.
4. In 38 percent of the opening strokes, no cuspal guidance occurred at all.
5. In 25 percent of the closing strokes, cuspal guidance was seen in the frontal as well as the sagittal views.
6. In 25 percent of the closing strokes, cuspal guidance occurred only in the frontal view.
7. Cuspal guidance in the sagittal view of the opening strokes was always in a protrusive direction and in the closing strokes in the retrusive direction.

III. THE ENVELOPE OF SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS SUBJECT 'A'

The frontal, sagittal and the horizontal elevations of the envelope of motion used during the three simulated chewing exercises, i.e., simulated chewing ad lib. on the right side and on the left side, were produced by superimposing the respective outline forms of the individual cycles of the exercises. (Fig. No. 39) The drawings were compared mutually and to the envelope of total movement space.

1. ENVELOPE OF MOTION DURING SIMULATED ad lib. CHEWING MOVEMENTS IN THE DENTULOUS SUBJECT 'A' (Fig. No. 39)

OBSERVATIONS:

All the three views of the envelope showed a well defined and compact movement space with smooth continuous outlines. The movements appeared to be following a smooth cyclic pattern.

Frontal View: (Fig. No. 39)

- (i) In the frontal view the occlusal end of the envelope of motion was almost a point. It extended 0.2 mm. to the left from the I.C.P.
- (ii) All the opening strokes passed on the left side and reached a maximum lateral deviation of 5.5 mm. from the C.V.A. close to the middle of the total vertical length of the envelope. The envelope reached maximum open position in a point 23.5 mm. from the I.C.P. and 1.7 mm. to the left of the C.V.A.
- (iii) The closing strokes initiated on the left side from the 'Point' maximally open position and crossed the C.V.A. to give a maximum lateral deviation of 2.0 mm. to the right of the C.V.A. at about the middle of the

vertical length of the envelope.

- (iv) The closing strokes reached the C.V.A. about 1.0 mm. from the I.C.P. and ended in the I.C.P. at right angles to the Y axis. Thus, most of the simulated ad lib. chewing movement space was located to the left side of the C.V.A. The closing strokes passed on the right side and closer to the C.V.A. than the opening strokes.
- (v) There was evidence of lateral cuspal guidance on the left or the opening side of the envelope. The fact that the closing strokes met the Y axis at 90° angle and at the I.C.P., precluded the possibility of any lateral cuspal guidance during the closing phase of these movements.
- (vi) Out of ten cycles recorded, two showed excessive lateral deviations. During the recording of controlled and simulated movements, it was observed that, at times, even though the controlling or guiding directions were being repeated, the subject executed one or two cycles quite out of character with the rest of the exercise. (Cycle No. 3, Figs. No. 36, 39) These were referred to as "freak cycles" and were possibly the result of a confusion between the external directives being repeated to the subject and the reflex directives originating from the proprioceptive sources located within the masticatory apparatus.

Sagittal View: (Fig. No. 39)

The envelope in its most part was located anterior to the X axis. Only the "maximally open end" of the envelope crossed posterior to the X axis. The pattern of the envelope is suggestive of a compulsory protrusive component complimenting the open/close movement.

Horizontal View: (Fig. No. 39)

The compact outline form is suggestive of efficient control over the ad lib. movements.

2. ENVELOPE OF MOTION DURING SIMULATED CHEWING MOVEMENTS
ON THE RIGHT SIDE IN DENTULOUS SUBJECT 'A' (Fig. No. 39)

OBSERVATIONS:

Frontal View:

- (i) The envelope of motion was much wider than that for the ad lib. exercise. This was due to (a) increased width of the individual cycles, and (b) variations in the direction of the cycles.
- (ii) The sides of the envelope showed considerable irregularities, and there were abrupt changes in the direction of motion.
- (iii) The movements did not show a regular cyclic pattern. The opening and closing strokes reached the I.C.P. from the right as well as the left side.
- (iv) Compared to the ad lib. sequence, the occlusal end of the envelope of motion was much wider. The right and left sides met the Y axis at 0.2 mm. and 0.6 mm. from the I.C.P. respectively. The marginal irregularities and excessive lateral deviation of the excursions reflect the hesitation of the jaw point during the excursions.

Sagittal View:

The outline extended posterior to the X axis for three quarters of the vertical length of the envelope. The antero-posterior depth of the sagittal view of simulated chewing movements on the right side was much greater than

that for the ad lib. movements, indicating that there was much greater antero-posterior shifting of the jaw point at maximal opening during this exercise.

Horizontal View: (Fig. No. 39)

The most distal extension of the envelope was located on the right side, and the extreme right lateral position in the envelope was located distally to the Y axis. The extreme lateral position on the left side of the envelope of motion was located anteriorly to the Y axis. The envelope of simulated chewing movements on the right side suggests that the subject did not perform these movements with as much control and proficiency as he did during the ad lib. movements.

THE ENVELOPE OF MOTION DURING SIMULATED CHEWING MOVEMENTS
ON THE LEFT SIDE IN DENTULOUS SUBJECT 'A'

The envelope was even wider and more irregular than for the movements on the right side. The individual cycles were performed in different directions and at different levels altogether. This was evident in all the three views of the envelopes, and indicates the subject's difficulty in performing the movements. Considering that the subject preferred to chew on the right side, the characteristics displayed appear quite justifiable.

SUMMARY AND DISCUSSION:

SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS SUBJECT 'A'

The characteristics of the simulated chewing movements in the particular dentulous subject examined can be summarised as follows:

For the ad lib. Chewing Exercise:

1. The movements initiated from and terminated in the intercuspal position.
2. The movements initiated with a sliding contact towards the left and followed a smooth cyclic pattern.
3. The opening strokes passed on the left side and reached maximal opening on the left side.
4. The closing strokes initiated on the left side, but crossed over to the right side and terminated directly in intercuspal position along the central vertical axis without any cuspal guidance.
5. The grinding phase of the chewing cycle appeared to be associated more with the opening stroke than the closing stroke. This style of a chewing cycle with the occlusal grinding forming a part of the opening stroke, and the closing stroke ending directly into the intercuspal position, can be referred to as the "reverse chewing cycle".
6. In the frontal view, the closing strokes passed closer to the C.V.A. than the opening strokes, while in the sagittal view, the opening and closing strokes passed virtually along the same path with a maximum antero-posterior distance of only 0.9 mm. between them, but generally anterior to the C.V.A. As the right side is the preferred side for mastication, there appeared to be a suggestion of a pattern, in that all the

SUMMARY AND DISCUSSION:

SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS SUBJECT 'A'

The characteristics of the simulated chewing movements in the particular dentulous subject examined can be summarised as follows:

For the ad lib. Chewing Exercise:

1. The movements initiated from and terminated in the intercuspal position.
2. The movements initiated with a sliding contact towards the left and followed a smooth cyclic pattern.
3. The opening strokes passed on the left side and reached maximal opening on the left side.
4. The closing strokes initiated on the left side, but crossed over to the right side and terminated directly in intercuspal position along the central vertical axis without any cuspal guidance.
5. The grinding phase of the chewing cycle appeared to be associated more with the opening stroke than the closing stroke. This style of a chewing cycle with the occlusal grinding forming a part of the opening stroke, and the closing stroke ending directly into the intercuspal position, can be referred to as the "reverse chewing cycle".
6. In the frontal view, the closing strokes passed closer to the C.V.A. than the opening strokes, while in the sagittal view, the opening and closing strokes passed virtually along the same path with a maximum antero-posterior distance of only 0.9 mm. between them, but generally anterior to the C.V.A. As the right side is the preferred side for mastication, there appeared to be a suggestion of a pattern, in that all the

closing strokes passed on the right side and were located closer to the median plane than the opening strokes.

In the sagittal view, although 50 percent of the closing strokes passed distally to the opening strokes, there was inconclusive evidence of a relationship between the farther distal extension of the envelope of total movement space on the preferred side and the antero-posterior location of the closing stroke within the envelope.

7. The pattern of the sagittal outline of the envelope is suggestive of a compulsory protrusive component, complimenting the open/close movement throughout its course from initiation to maximal opening.
8. The compactness and a smooth well defined continuous outline form of the envelope of ad lib. chewing exercises implies adequate proficiency and control over the movements by the subject.

For the Simulated Chewing Movements on the Right and Left Sides:

1. Unlike the ad lib. simulated chewing movements, the simulated chewing movements on the right and left sides did not appear to conform to any particular pattern. This was shown by the positional relations of the opening and closing strokes as well as the role of cuspal guidance and the envelope of motion used. The only common factor was that all the movements initiated from and terminated in the intercuspal position. The opening strokes initiated on the ipsilateral as well as the contralateral sides. Likewise, the maximum opening was reached on the

ipsilateral and the contralateral sides, but in 87.5 percent of the cycles, the point of maximum opening was located on the same side as the initiation of the opening strokes. There was no relationship between the location of the opening and closing strokes and the preferred side for mastication.

2. Cuspal guidance occurred in all the cycles, either in both the opening and closing strokes, or at least in one of the strokes in the frontal or sagittal, or both the views.

Whereas the outline form of the envelope for ad lib. simulated chewing created an impression of compactness of form, smoothness and co-ordination of operation, the envelope for chewing on the right side was much wider and more irregular, suggesting difficulty and hesitation on the part of the subject in performing these movements. The envelope of simulated chewing on the left side was even wider and more irregular than on the right side. The different directions and different planes of the individual cycles suggest that the subject experienced difficulty in performing the exercise.

The study of simulated chewing movements helped to formulate a procedure for the assessment of functional movements.

SIMULATED CHEWING MOVEMENTS IN THE EDENTULOUS SUBJECTS

The frontal, sagittal and horizontal views for four consecutive cycles from each of the three exercises i.e., the ad lib. chewing, chewing on the right side and chewing on the left side, were plotted on the graphs, for the four edentulous subjects. (Figs. No. 40-47).

These were examined in a manner similar to that followed for the dentulous subject.

POSITIONAL RELATIONSHIP OF THE OPENING AND CLOSING STROKES IN EDENTULOUS SUBJECTS B, D, D AND E:

1. Simulated ad lib. Chewing Exercise: (Figs. No. 40, 43, 44, 45)

Frontal View:

- (a) All the cycles initiated from and terminated in closed mouth zero position.
- (b)
 - (i) 56 percent of the opening strokes initiated on the right side.
 - (ii) 19 percent of the opening strokes initiated on the left side.
 - (iii) 25 percent of the opening strokes initiated directly along the C.V.A.
- (c) The maximum opening was reached on the right side in 81 percent of the opening strokes. In 19 percent of the cycles, the maximal opening was reached directly on the C.V.A.
- (d) In three of the four subjects, the maximum opening was a point position. The jaw point came to a stop and without loss of time reversed its direction of motion. In one subject, the jaw point performed loops to change its direction of motion.

- (e) (i) In 50 percent of the cycles, the closing stroke remained on the right side of the C.V.A.
- (ii) In 25 percent of the cycles, the closing stroke remained on the C.V.A.
- (iii) In 25 percent of the cycles, the closing strokes crossed over to the left side.
- (f) (i) In 50 percent of the cycles, the closing strokes passed closer to the C.V.A. than the opening strokes.
- (ii) In 25 percent of the cycles, the opening and the closing strokes overlapped each other in the frontal view and both passed along the C.V.A.
- (iii) In 25 percent of the cycles, the closing strokes passed further laterally from the C.V.A. than the opening strokes.

Sagittal View:

- (a) (i) 88 percent of the opening strokes initiated from the intercuspal position. (This was confirmed by comparing the Frontal and Sagittal Views)
- (ii) 12 percent of the opening strokes initiated from points located further posteriorly to the intercuspal position on the Z axis.
- (b) (i) 81 percent of the opening strokes passed posteriorly to the C.V.A. from their points of initiation.
- (ii) 19 percent of the opening strokes passed anteriorly to the C.V.A. at their points of initiation.
- (c) (i) 93 percent of the closing strokes initiated from maximally open positions located distally to the C.V.A.
- (ii) 7 percent of the closing strokes initiated from maximally open positions located on the C.V.A.

- (d) In all the cycles, the maximal opening was a point position.
- (e) (i) 69 percent of the closing strokes remained posterior to the C.V.A. throughout their course.
(ii) 31 percent of the closing strokes passed anteriorly to the C.V.A. for at least part of their course.
- (f) In 56 percent of the cycles, the closing strokes passed distally to the opening strokes.
- (g) (i) 81 percent of the closing strokes terminated in intercuspal position.
(ii) 19 percent of the closing strokes terminated in positions located posteriorly to the intercuspal position.

The observations in the horizontal views confirmed the observations made in the frontal and sagittal views.

2. Simulated Chewing on the Right and Left Sides:
(Figs. No. 41, 42, 43, 45, 46, 47)

Frontal View:

- (a) (i) 77 percent of the cycles initiated from the zero point.
(ii) 23 percent of the cycles initiated from positions on the left side.
- (b) (i) 66 percent of the opening strokes initiated on the ipsilateral side.
(ii) 34 percent of the opening strokes initiated on the contralateral side.
- (c) (i) 74 percent of the opening strokes reached maximal opening on the ipsilateral side.

- (ii) 26 percent of the opening strokes reached maximal opening on the contralateral side.
 - (iii) In 67 percent of the cycles, the maximal opening was located on the same side as the initiation of the opening strokes.
 - (iv) In 33 percent of the cycles, the maximal opening was reached on the side opposite to the side of the initiation of the opening stroke.
- (d)
- (i) In 74 percent of the cycles, the maximal opening was a point position. The jaw point came to a stop and then immediately reversed its direction of motion.
 - (ii) In 26 percent of the cycles, the jaw point moved laterally and horizontally at maximal opening and then changed its direction of motion into the closing stroke.
- (e)
- (i) In 96 percent of the cycles, the closing stroke was located fully, or at least in its occlusal half of the total length, on the ipsilateral side.
 - (ii) In 4 percent of the cycles, the closing strokes passed on the contralateral side.
- (f)
- (i) In 35 percent of the cycles, the closing stroke passed closer to the C.V.A. than the opening stroke.
 - (ii) In 65 percent of the cycles, the closing strokes passed farther away from the C.V.A. than the opening strokes.
- (g)
- (i) 74 percent of the closing strokes terminated in the zero position.
 - (ii) 26 percent of the closing strokes ended up in positions other than the zero point on the left side.

- (iii) 38 percent of the simulated chewing cycles on the left side and 13 percent of the cycles on the right side ended in positions other than the zero point.
- (iv) In 13 percent of the cycles, the closing strokes stopped short of the Y axis, ending in open mouth positions.

Sagittal View:

- (a)
 - (i) Although 81 percent of the opening strokes initiated from the zero point, only 65 percent actually initiated from the intercuspal position.
 - (ii) 6 percent of the opening strokes initiated from open mouth positions.
 - (iii) 13 percent of the opening strokes initiated from positions located posteriorly to the zero point.
- (b)
 - (i) 94 percent of the opening strokes passed posteriorly to the C.V.A.
 - (ii) 6 percent of the opening strokes passed anteriorly to the C.V.A.
- (c)
 - (i) 94 percent of the closing strokes initiated from maximally open positions located distally to the C.V.A. in the sagittal view.
 - (ii) 3 percent of the closing strokes initiated from points located anteriorly to the C.V.A.
 - (iii) 3 percent of the closing strokes initiated from positions located on the C.V.A.
- (d) An equal number of cycles showed 'Point' and 'Loop' forms at maximal opening.
- (e)
 - (i) 74 percent of the closing strokes passed posteriorly

- to the C.V.A.
- (ii) 26 percent of the closing strokes passed anteriorly to the C.V.A. in part, or as a whole.
- (f)
- (i) 48 percent of the closing strokes passed posteriorly to the opening strokes.
 - (ii) 45 percent of the closing strokes passed anteriorly to the opening strokes.
 - (iii) 7 percent of the opening and closing strokes coincided with one another in the sagittal view.
- (g) 77 percent of the closing strokes ended on the C.V.A. in the sagittal views; of these, 17 percent terminated short of the Z axis in open mouth positions.

II. ROLE PLAYED BY CUSPAL GUIDANCE DURING SIMULATED CHEWING MOVEMENTS IN EDENTULOUS SUBJECTS, B, C, D, and E

Following the procedures described earlier, tangent angles for the opening and closing strokes during ad lib. simulated chewing, simulated chewing on the right side, and simulated chewing on the left side were measured and compared with the maximal cuspal guidance angles for the particular subject. (Table No. 16)

A total number of 63 cycles were examined. The presence or absence of cuspal guidance was determined. Tables No. 17, 18 and 19 show the tangent angles and the incidence of cuspal guidance. The observations made are shown in Tables No. 20 and 21.

The opening strokes during ad lib. simulated chewing show the maximal incidence of cuspal guidance, and 75 percent of the opening strokes were preceded by intercuspal grinding.

63 percent of the ad lib. opening strokes showed cuspal guidance only in the frontal view, indicating a predominantly lateral movement of the jaw point.

Only 6 percent of the opening strokes during ad lib. chewing showed cuspal guidance in the sagittal view in two subjects. In Subject 'B', it represented a protrusive grinding (Fig. No. 40, Cycle No. 1). In Subject 'D', it represented a retrusive grinding movement. (Fig. No. 44, Cycle No. 2)

6 percent of the ad lib. opening strokes showed cuspal guidance in both the frontal as well as the sagittal views. This indicates a simultaneous lateral and protrusive grinding excursion of the mandible against the maxilla.

50 percent of the closing strokes during ad lib. simulated chewing showed some cuspal guidance. 25 percent of the closing strokes showed cuspal guidance only in the frontal view, 19 percent showed cuspal guidance only in the sagittal view. 6 percent of the closing strokes showed cuspal guidance in both the frontal as well as the sagittal views. In Subject 'C', (Fig. No. 43, ad lib. Cycle No. 3) cuspal guidance in the sagittal view indicated a protrusive grinding excursion during the terminal parts of the closing stroke.

The incidence of cuspal guidance in the simulated chewing exercises on the right and left sides was much lower than during ad lib. exercises. (Tables No. 20 and 21) Whereas 94 percent of the ad lib. cycles showed cuspal guidance during the opening and closing strokes, the incidence during simulated chewing on the right and left sides was only 61 percent.

During simulated chewing exercises, the subject was

expected to perform grinding movements at some stage of the cycle. The incidence of cuspal guidance during these exercises, represents the proficiency of performance.

III. ENVELOPE OF MOVEMENT SPACE USED DURING SIMULATED CHEWING EXERCISES IN EDENTULOUS SUBJECTS, B, C, D and E

The frontal, sagittal and horizontal views of the envelopes of movement space used during the three simulated exercises, i.e., simulated chewing ad lib., on the right side and on the left side, in four edentulous subjects, were developed following the procedure adopted for the dentulous subject. (Figs. No. 48, 49) The following observations were made:

1. There were considerable individual variations in the size, shape and form of the envelopes of space used by the different subjects. Whereas Subject 'B' presented the maximal dimensions, in all the four directions, in Subject 'D' the simulated ad lib. movements followed straight up/down paths along the central vertical axis in the frontal view, without any lateral deviations, and in the sagittal view presented the least amount of space used in the antero-posterior direction.
2. In all the edentulous subjects, the envelope of space used was much smaller than used by the dentulous Subject 'A'.
3. The envelope of space used by the edentulous subjects was generally not as smooth and compact as in the dentulous subject, and the space used during simulated chewing on the right and left was comparatively more irregular than that used during ad lib. exercises.
4. In all the edentulous subjects, during ad lib. chewing exercises, and chewing exercises on the right side, most

of the space used was located on the right side of the central vertical axis. During simulated chewing exercises on the left side, most of the space used was located on the left side.

5. In the sagittal view of all of the edentulous subjects, most of the movement space was located distal to the central vertical axis. The distal boundary of the envelope generally showed a distal convexity.
6. In all the edentulous subjects, the occlusal ends of the envelope of movement space used during simulated chewing extended some distance from the intercuspal position in the right/left and antero-posterior directions. (Table No. 22). Thus, the occlusal ends of the envelope of movement space used during simulated movements were flat surfaces, and the intercuspal position was located in the middle of these surfaces.
7. Disposition of the opening and closing strokes in the envelope of movement space depended upon the chewing exercise being performed as well as the subject's individual style of performance. During ad lib. chewing exercises, most of the opening and closing strokes passed on the right side of the envelope of movement space, while during chewing exercises on the sides most of the opening and closing strokes remained confined to the ipsilateral side. (Table No. 23)

SUMMARY AND DISCUSSION:

SIMULATED CHEWING MOVEMENTS IN THE EDENTULOUS SUBJECTS B, C, D, E

POSITIONAL RELATIONS OF THE OPENING AND CLOSING STROKES:

Simulated ad lib. Chewing:

1. Whereas in the dentulous Subject 'A' the simulated ad lib. chewing cycles initiated from, and terminated only in the intercuspal position, in the edentulous subjects the movements initiated from, and terminated in either (i) intercuspal position, or (ii) positions located further distal to the intercuspal position.
2. A majority of the opening strokes passed on the right side or along the C.V.A. in the frontal view, and distally to the C.V.A. in the sagittal view. A lesser number of opening strokes passed on the left side in the frontal view and anteriorly to the C.V.A. in the sagittal view.
3. The cycles generally followed a smooth cyclic pattern in an anti-clockwise direction. Clockwise movement was also seen. It occurred as a pattern in some subjects and as a variation of the pattern in the sequence in others.
4. The maximally open position was generally located on the right side, or on the C.V.A. in the frontal view, and posterior to the C.V.A. in the sagittal view.
5. Most of the closing strokes remained on the right side or passed along the C.V.A. in the frontal view and distally to it in the sagittal view.
6. A majority of the closing strokes passed closer to the

C.V.A. than the opening strokes in the frontal view, and farther distally in the sagittal view.

Simulated Chewing on the Right and Left Sides:

1. The points of initiation and termination of the cycles were even more dispersed than in the ad lib. cycles. The opening strokes initiated from the: (i) intercuspal position, (ii) open mouth positions, (iii) positions located on the left side, as well as (iv) positions located posterior to the C.V.A.
2. Most of the opening strokes initiated on the ipsilateral side.
3. Most of the opening strokes reached maximal opening on the ipsilateral side in the frontal view, and distal to the C.V.A. in the sagittal view.
4. In a great majority of the cycles, the closing strokes passed on the ipsilateral side in the frontal view and distal to the C.V.A. in the sagittal view.
5. Most of the closing strokes passed farther away from the C.V.A. than the opening strokes in the frontal view, and farther distally in the sagittal view.

II. ROLE OF CUSPAL GUIDANCE:

1. Cuspal guidance occurred at the initiation of the opening strokes and also at the end of the closing strokes. The incidence was greater in the former than in the latter.
2. Cuspal guidance occurred from: (i) medial to lateral, as during opening strokes, (ii) lateral to medial as

during closing strokes, (iii) in a protrusive direction, and also (iv) in a retrusive direction. The protrusive and retrusive cuspal guidance were seen in the sagittal view and were associated both with the opening as well as the closing strokes. The incidence of such cuspal guidance was much lower than the lateral cuspal guidance.

3. Whereas in the dentulous subject, protrusive cuspal guidance was associated with the opening strokes and retrusive cuspal guidance with the closing strokes, in the edentulous subjects the relationship was reversed. The incidence of retrusive cuspal guidance was greater during the opening strokes, and the incidence of protrusive cuspal guidance was greater during the closing strokes.
4. The incidence of cuspal guidance was also suggestive that a subject was capable of performing four different patterns of chewing cycles. These are:
 - (i) The chewing cycles initiating directly without any cuspal guidance during the opening strokes, but the closing strokes terminating with cuspal guidance. Such cycles can be referred to as "Conventional Chewing Cycles".
 - (ii) The cycles initiating with cuspal guidance preceding the opening strokes, and terminating with the closing strokes reaching the close-mouth position directly without any cuspal guidance, such cycles can be referred to as "Reverse Chewing Cycles".
 - (iii) The chewing cycles initiating and terminating with cuspal guidance at both ends. Such cycles can be referred to as "Double Chewing Cycles".

- (iv) The opening and closing strokes initiating and terminating directly without any cuspal guidance at any stage of the cycle. Such cycles can be referred to as "Direct Chewing Cycles".

III. ENVELOPE OF MOVEMENT SPACE:

1. The envelope of movement space used during simulated chewing exercises varied in different subjects, both in size as well as form.
2. In the edentulous subjects, the envelope was generally smaller than in the dentulous subject.
3. In the edentulous subjects, the envelope was not as compact as in the dentulous subject. The different cycles followed different directions, indicating some degree of loss of control.
4. During ad lib. chewing, the subjects generally used the space on their preferred side for mastication. During chewing exercises on the designated sides, the movements generally took place on the ipsilateral side.
5. In the sagittal view, most of the movement space was located distally to the C.V.A.
6. There was a strong suggestion that, during ad lib. simulated chewing exercises, the edentulous subjects used the posterior quadrant on the preferred side more often than on the non-preferred side.
7. Unlike the dentulous subject, the occlusal end of the envelope of movement space in the edentulous subjects was not a "point". It could be visualised as a flat surface with lateral and antero-posterior dimensions and the intercuspal position was located in the middle

of this area. The occlusal end of the envelope extended on an average, 0.9 mm. to the right and left sides of the intercuspal position, 0.3 mm. to the distal and 0.2 mm. anteriorly.

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SECTION VII

MASTICATORY MOVEMENTS

IN DENTULOUS AND EDENTULOUS SUBJECTS

MASTICATORY MOVEMENTS IN THE DENTULOUS AND
EDENTULOUS SUBJECTS

Four ad lib. masticatory exercises involving three different foods, i.e. peanuts, meat and hard sugar drops were examined.

METHOD OF RECORDING:

1. Confirmation of the Intercuspal Position:

This was achieved by asking the subject to open and close his teeth several times while observing the position of the writing pens on the recording paper. The most consistently and automatically acquired position was considered to be the maximally intercusped maxillo-mandibular relationship. The position of the pens was so adjusted that they aligned as closely as possible to the millimetre ruling on the three channels of the recording paper, thus providing a base line from which deviations could be easily measured.

2. Placement of the Food:

The food was placed on the tongue and the subject closed his teeth together. By observing the position of the writing pens it was ascertained that the teeth closed in the maximally intercusped position. This maxillo-mandibular relationship was recorded on the mandibulograph.

3. Mastication of Food:

The instruction to commence mastication of food was given a few seconds after the recording of the intercuspal position. The subject opened his mouth, shifted the food to the teeth with his tongue on the side of his preference and chewed as he pleased, no restrictions being imposed in respect to the side or the number of chews.

The subject masticated the food until he was ready to swallow. He was allowed to perform the "involuntary swallow" then instructed to swallow again and hold his teeth together in the relationship acquired during the second swallow. The mandibulograph recording was stopped shortly after the second swallow.

4. Foods Used:

Roasted peanuts, grilled beef steak, and hard sugar drops were the three foods used.

- (i) Roasted peanuts were selected because of their soft and brittle nature. They could be expected to break down after the first few masticatory cycles and mix with saliva to form a paste which required further chewing but did not produce severe occlusal table jamming. A single half of a medium sized kernel was used to provide an early occlusal clearance so that the movements of the jaw point in the terminal parts of the masticatory cycle could be examined with the least amount of food between the teeth.

For the full mouth peanut chewing test, six medium-sized half kernels were used, the objective of this exercise being portrayal of a more natural functional performance.

- (ii) Grilled beef steak was used because of its firmness and toughness, and the fact that the bolus maintained its shape for a longer period. The beef steak was cut up into approximately 1.0 cm. cube pieces.
- (iii) Sugar drops were used for their hard and brittle

consistency and the fact that they tended to jam the occlusal surfaces of the teeth, creating a traumatic circumstance quite frequently encountered during natural function. The sugar drops were cut up into approximately 0.5 cm. cube pieces.

All recordings were carried out at a paper speed of 25 mm/sec.

5. Masticatory Exercises:

The following four exercises were recorded for the two types of subjects:-

1. Single Peanut Chewing ad lib. (P.C. ad lib.):
Dentulous Subject = 12 Cycles
Edentulous Subjects = 94 Cycles
2. Full-mouth Peanut Chewing ad lib. (P.C.F.M. ad lib.)
Dentulous Subject = 26 Cycles
Edentulous Subjects = 66 Cycles
3. Meat Chewing ad lib. (M.C. ad lib.):
Dentulous Subject = 22 Cycles
Edentulous Subjects = 85 Cycles
4. Sugar Drop Chewing ad lib. (S.D.C. ad lib.):
Dentulous Subject = 15 Cycles
Edentulous Subjects = 83 Cycles

75 masticatory cycles for the Dentulous Subject 'A' and a total of 328 masticatory cycles for the four Edentulous Subjects 'B', 'C', 'D' and 'E' were recorded on the mandibulograph.

Subject 'D' could not manage the "P.C.F.M. ad lib." and "S.D.C. ad lib." exercises. The larger size of bolus in the former exercise interfered with his manipulation of the dentures and the exercise could not be recorded. In the latter exercise the bolus

proved too hard for the subject to break through. The subject made a few attempts but finally rejected the bolus. The exercise was nevertheless recorded and assessed.

METHODS OF ASSESSMENT:

The kinematic masticatory performances of the Dentulous and Edentulous subjects were assessed in two ways:

1. Visual Observation During Performance:

The subjects were observed during the performance of the exercises and subsequently asked to describe the sequence of events that took place in the mouth. Similar exercises were also performed by the author to verify and confirm the descriptions given by the subjects.

2. Detailed Assessment of the Masticatory Cycles:

Visual observations of masticatory exercises during performance and initial examination of the recordings revealed that masticatory movement patterns changed as the masticatory sequence progressed from initiation to termination. On the evidence of these changes each masticatory sequence could be divided up into three sections i.e. the initial or "1st Phase", the intermediate or "2nd Phase" and the terminal or "3rd Phase".

With the exception of the beginning of the 1st Phase and the termination of the 3rd Phase, which obviously formed the beginning and ending of the masticatory sequence, the phases did not have any sharp and definite boundaries in respect to time of occurrence, duration of performance or the number of cycles per phase. An arbitrary number of 3 to 5 consecutive cycles at the beginning and ending of the sequence were chosen to represent the 1st and 3rd

Phases. From the intervening part of the sequence 4 to 6 consecutive cycles that showed some mutual resemblance were chosen to represent the 2nd Phase.

In Subject 'A' the "P.C. ad lib." sequence involved only 12 masticatory cycles, so the division had to be in four consecutive cycles for each phase. Other sequences lasted longer and the boundaries of the 2nd Phase were based upon apparent resemblance in the mandibulograph recordings.

Frontal and sagittal views of a total number of 56 Dentulous and 215 Edentulous masticatory cycles were plotted on the graphs from the mandibulograph tracings by the subjects. (Figs. No. 50-74)

Similar to the assessment of the simulated chewing movements, each of the masticatory cycles were examined for:

- I. Positional relationships of the opening and closing strokes.
- II. Role of cuspal guidance.
- III. Envelope of movement space used.

I. Positional Relationships of the Opening and Closing Strokes:

Following the procedure laid down for the examination of the simulated movements, the percentage incidence of variations of the features 'a' to 'g' as detailed on pages No. 100 to 103 were determined and tabulated as:

- (i) Percentage incidence of variations during each of the four exercises in the Dentulous Subject: Tables No. 24 to 30.
- (ii) Percentage incidence of variations in the total performance by the Dentulous Subject: Tables No. 24 to 30.

- (iii) Percentage incidence of variations during the three phases of the total performance by the Dentulous Subject: Tables No. 31 to 37.
- (iv) Percentage incidence of variations in the total performance of the four individual Edentulous Subjects: Tables No. 40 to 46.
- (v) Percentage incidence of variations in the total performance of the total Edentulous Sample: Tables No. 40 to 46.
- (vi) Percentage incidence of variations during each of the three phases of the total performance by the total Edentulous Sample: Tables No. 47 to 49.
- (vii) Percentage incidence of variations during the three phases of each of the four exercises by the total Edentulous Sample: Tables No. 50 to 77.
- (viii) Percentage incidence of variations during the total performance of each of the four exercises by the total Edentulous Sample: Tables No. 50 to 77.

All Tables are presented as Appendix II in Vol. II.
The data was compiled to show:

1. General characteristics of masticatory movements and their variations in the Dentulous and Edentulous States.
2. Variations of the characteristics in respect to the three phases of the masticatory sequence.
3. Variations of the characteristics in respect to variations of food consistencies and quantities.

Similar to the examination of the simulated chewing movements the assessment of the positional relationships of the opening and closing strokes of masticatory cycles was based on 44 observations for each cycle from initiation

to its termination. But the number of observations increased to as many as 150 per cycle when variations in respect to individual subjects, total sample performance, phases of masticatory sequences and consistencies and quantities of food were involved. It would be impossible to compare so many observations without further condensation or simplification.

The main objective of these observations was to test the hypothesis that the mandible recedes to the posterior quadrant of the envelope of total movement space on the preferred side when called upon to perform under conditions involving greater masticatory stresses, and that this tendency is more pronounced in the edentulous state than in the dentulous state, and is provided for by a further distal extension of the envelope of total movement space on the preferred side. Accordingly, all spatial observations (e.g. shown in Tables No. 24 - 30 for the Dentulous Subject 'A') were interpreted in terms of their proximity to or remoteness from the posterior quadrant on the preferred side. These were expressed as percentage incidence during the performance. The percentage of observations within the preferred posterior quadrant or on the C.V.A. was considered positive, and those outside the preferred posterior quadrant, negative. Thus the observations could be condensed to a single value which measured approximately the tendency for the subject or the entire sample to exhibit a positional preference during total performance or a particular performance, in respect to the posterior quadrant on the preferred side. This tendency was referred to as the "Positional Preference Index" and was calculated in the following manner:

- i. The subject's preferred side for mastication was determined. (Both dentulous and edentulous subjects shifted the food to between the teeth on the right side during ad lib. mastication which was considered to be the preferred side for mastication.)
- ii. Treating the dentulous subject as an example, in Tables No. 24-26 and 28 and 30 (showing variations of the features a, b, c, e, and g, indicating the positional relationships of the opening and closing strokes to the intercuspal position and the C.V.A.) the vertical columns No. 1, 3, 4, 7 and 8 show occurrence of the features along the C.V.A. or in the posterior quadrant on the preferred side in the total envelope of movement space. Accordingly the observations in these columns were given positive values. Observations in the columns No. 2, 5 and 6, indicating occurrence of the features on the non-preferred side and/or anterior to the C.V.A. were given negative values.
- iii. Observations in respect to the feature 'f' i.e. mutual positional relationship of the opening and closing strokes to the C.V.A. (Table No. 29) in vertical columns No. 3 and 6, were given negative values, as theoretically these indicated a comparatively insecure course of the closing stroke in the particular cycle, being farther away from the C.V.A. than the opening stroke in the frontal view and farther anteriorly to the opening stroke in the sagittal view. Observations in other columns were given positive values.

- iv. Feature 'd' (Table No. 27) was not included in this assessment, as the form of the maximally open position classified a functional quality of the masticatory cycle only.
- v. The figures in these columns indicate percentage incidence of particular positional relationships of particular parts of the cycles in a particular sequence or performance. The total of these figures, after considering the positive and negative values, was divided by the number of observations i.e. 40. The resultant figure could be positive or negative depending upon whether the positive or negative features dominated the performances.

A highest positive figure of +35 for individual cycles, phases, sequences or the entire performance indicated that the entire movement during the cycle, and in all the cycles of the phases, sequences or the total performance occurred in the posterior quadrant of the envelope of total movement space on the preferred side. A smaller positive numerical value indicated that a part of the movement in the same cycle, or in some of the cycles in a phase, sequence or total performance, extended into the non-preferred sections of the envelope of total movement space.

A highest figure of -35 indicated that the entire movement in the cycles, phases, sequences or total performance took place in the non-preferred parts of the envelope of total movement space. This would be a hypothetical situation indicating that the preference for the side for chewing was incorrectly determined. A lesser negative numerical value indicated that the movement at some stage of performance had extended into the posterior quadrant on the

preferred side. Thus performances on the non-preferred side but posterior to the C.V.A. or on the preferred side but anterior to the C.V.A. showed lesser negative numerical values.

Similarly a zero value indicated that the movements were evenly dispersed in the preferred and non-preferred parts of the total movement space.

These resultant positive or negative figures reflect the degrees of subconscious control exercised by the subject in the selection of the location and direction of movements in relation to the base of skull, the prime objectives being self-preservation and maximal efficiency. The figures can be referred to as "Postiional Preference Index" and may be interpreted to express a "Conservative Performance" when showing a positive value and a "Non-Conservative Performance" when showing a negative value.

A "Conservative Performance" of a masticatory sequence is defined as a performance in which a majority of the masticatory cycles either in full or in part satisfy most of the following conditions:

- a. Initiate from intercuspal position or closed-mouth positions located posterior to the C.V.A. and on the preferred side.
- b. The opening strokes commence on the preferred side and posterior to the C.V.A. and
- c. Reach maximally open positions on the preferred side and posterior to the C.V.A.
- d. May show "Point" or "Loop" form maximal openings.
- e. The closing strokes pass on the preferred side and posterior to C.V.A.

- f. The closing strokes pass closer to the C.V.A. than the opening strokes and posterior to them.
- g. The closing strokes terminate in intercuspal position or closed-mouth positions located posterior to the C.V.A. on the preferred side.

The greater or lesser degree of conservative performance would be indicated by the higher or lower positive figures respectively.

A "Non-Conservative Performance" can be defined as a performance in which most of the masticatory cycles are executed either in full or in part on the non-preferred side and/or anterior to C.V.A., thus, at least theoretically, exposing the movable component of the masticatory apparatus to possible traumatic conditions (Page 96). It is not within the scope of this investigation to decide whether such situations could be actually traumatic or not. The most that can be said is that the mandible performed from or in theoretically insecure areas.

The Positional Preference Index (P.P.I.) figures have been used to express the characteristics of:

1. Total performance in the Dentulous and Edentulous States during the entire experiment.
2. Total performance in the individual subjects during the entire experiment.
3. Variations of the performance during the three phases of sequences in the Dentulous and Edentulous States.
4. Variations of the performance in respect to variations in food consistencies and quantities in the Dentulous

and Edentulous subjects.

II. Role of Cuspal Guidance During Masticatory Movements:

It was found that a considerable number of masticatory cycles in the Dentulous performance and also in the Edentulous performance initiated from and terminated in open-mouth positions with food between the teeth. For this reason, the tangent angle measurements as used for the simulated chewing movements did not give any conclusive evidence of whether or not cuspal guidance played any part in the masticatory sequences.

On the assumption that cuspal guidance, when and where it occurs, must necessarily be a border position, the frontal and sagittal outline forms of individual masticatory cycles were compared to the frontal and sagittal views respectively of the lateral and protrusive sliding contact border excursions in the total envelope of movement space in the particular subject.

The frontal views of lateral occlusal border excursions and sagittal views of protrusive occlusal border excursions of each subject were traced on translucent tracing paper, with 'X', 'Y' and 'Z' axes marked. These transparencies were to the same scale as the outline forms of the masticatory cycles (5 mm. = 1") and could be aligned to the masticatory movement outline forms by alignment of the axes. The points on the outline form of the masticatory cycle which corresponded to the border outline form on the transparency were considered points of occlusal contact or points of cuspal guidance. The type of cuspal guidance could also be determined by comparing the two outline forms. As indicated above the actual assessments were made on drawings magnified to the

scale of 5 mm. = 1", but for inclusion in this work, were photographically reduced. The reduced transparencies have been reproduced on acetate film and appended as Figs. No. 75 and 76 (Vol. II)

The observations were tabulated as:

1. Percentage incidence of cuspal guidance during masticatory exercises in individual subjects:
Dentulous Subject: Table No. 38.
Edentulous Subjects: Tables No. 78 to 81.
2. Percentage incidence of cuspal guidance in the total performance by individual subjects.
Dentulous Subject: Table No. 38.
Edentulous Subjects: Tables No. 78 to 81.
3. Degree of involvement of cuspal guidance in the masticatory cycle.
This was considered to be indicated by: (i) cuspal guidance only in the opening stroke, (ii) cuspal guidance only in the closing stroke, (iii) cuspal guidance involving the opening and closing strokes of the same cycle, and (iv) cuspal guidance involving both the strokes of the same cycle and apparent in both the frontal and sagittal views.
Dentulous Subject: Table No. 38.
Edentulous Subjects: Tables No. 78 to 81.
4. Percentage incidence and degree of involvement of cuspal guidance in the three phases of the four masticatory exercises.
Dentulous Subject: Table No. 38.
Edentulous Subjects: Tables No. 82 to 85.
5. Types of cuspal guidance.
Dentulous Subject: Table No. 39.
Edentulous Subjects: Tables No. 86 to 89.

III. Envelope of Movement Space Used:

The frontal, sagittal and horizontal views of the envelopes of movement space used by the individual subjects during the masticatory exercises were developed in a manner similar to that of the simulated movements.

Dentulous Subject: Figs. No. 60 and 61.

Edentulous Subjects: Figs. No. 66 to 74.

The examination consisted of:

1. Observation of general features of shape and form.
2. Location of intercuspal position in relation to the envelope of movement space used.

OBSERVATIONS

VISUAL OBSERVATIONS DURING PERFORMANCE

Each exercise created different conditions and situations in the mouth. The following information was gathered from the subjects and by the author when performing the exercise for himself:

1. Single Peanut Chewing ad lib. (P.C. ad lib.):

The size of the bolus was very small. An average sized half kernel used did not exceed 17 mm. in length, 7 mm. in width and about 3 mm. in thickness.

The food was crushed in the first closing stroke. Some of the crushed food particles remained on the occlusal surfaces, some remained around the occlusal surfaces and some were carried on the tongue.

During the subsequent cycles the subject attempted to

- (i) displace the particles of crushed food from the occlusal surfaces,

- (ii) replace the larger sized particles located close to the occlusal table onto the occlusal surface for further comminution, and
- (iii) search for larger-sized particles and relocate these on the occlusal surfaces.

The size of the bolus was so small that mastication was performed only on the preferred side.

2. Full Mouth Peanut Chewing ad lib. (P.C.F.M. ad lib.):

Six half kernels of the same size as for the "P.C. ad lib" exercise were used, forming a bolus of some size, especially for the edentulous subjects.

The initial crushing of the food extended over a greater number of cycles. The crushed food formed a thicker paste than in the "P.C. ad lib." exercise, this thicker paste permitted the larger food particles to be held closer to the occlusal table on the preferred side and made more easily available for further crushing. The presence of a greater amount of food resulted in a more or less automatic clearance of the occlusal table. The food crushed in the latter closing strokes displaced the crushed food already on the occlusal table. Some food particles escaped from the paste and were carried to the opposite side for further crushing. This generally happened later in the sequence but could not be pinpointed. The edentulous subjects reported less food jamming the occlusal surfaces, possibly because of shallower occlusal anatomy and also because acrylic teeth were used. The high polish on the teeth appeared to reduce adhesion of food to the surfaces. The edentulous Subject 'D' could not manage this exercise.

3. Meat Chewing ad lib. (M.C. ad lib.):

A 1 cm. cube piece of meat formed a rather small-sized bolus so mastication remained confined to the preferred side, and the bolus maintained a shape throughout the sequence. The mastication of the small bolus of meat resembled very much the tenderising action of a mallet on a piece of steak. The meat bolus was punctured, softened and frequently rolled and turned over in the mouth for thorough impregnation with saliva.

4. Sugar Drop Chewing ad lib. (S.D.C. ad lib.):

Even though the size of the bolus was very small only the dentulous and one edentulous subjects were able to crush the food in the first stroke. Edentulous Subject 'D' rejected the food after a few unsuccessful attempts, but the remaining three edentulous subjects were able to crush the food after repositioning it several times. The subsequent cycles were spent in dislodging the crushed food jamming the occlusal surfaces. Although the crushed food bolus was being dissolved, continuously on its surface, thus decreasing in size; it maintained a form until quite late in the sequence.

All the subjects during all the four exercises chewed the food on the right side. As the four exercises were ad lib. performances this was taken to indicate that the subjects preferred the right side for mastication.

DETAILED ASSESSMENT OF THE MASTICATORY CYCLES

The figures and tables of observations with explanations are presented as appendices I and II in Vol. II.

I. Positional Relationships of the Opening and Closing Strokes:
Total Sample Performances in the Dentulous and Edentulous
Subject:

Dentulous Subject:- (Figs. No. 50 to 59 and Tables No. 24-30)

- a. (i) In the particular subject, only the first cycle of each sequence initiated from closed-mouth and intercuspal position, all subsequent cycles initiated from open-mouth positions.
- (ii) The masticatory cycles generally initiated from open-mouth positions located on the C.V.A. both lateromedially as well as anteromedially as well as anteroposteriorly.
- b. The opening strokes generally initiated on the left side (non preferred side) and anterior to the C.V.A. A lesser number of opening strokes also commenced on the right side (preferred side) and posterior to the C.V.A.
- c. The maximal opening was generally reached on the left side (non preferred side) and anterior to the C.V.A., though a considerable number of opening strokes also ended on the right side (preferred side) and posterior to the C.V.A.
- d. The maximally open position was generally a "point" position in the frontal as well as the sagittal views. "Loop" formation was also seen, though mostly in the frontal view.

The "Point" position at maximal opening in the frontal and sagittal views indicated absence of any lateral or anteroposterior movement of the jaw point at that level. "Loop" formations indicated lateral or anteroposterior excursions of the jaw point when these occurred in frontal or sagittal views respectively.

A progressively increasing incidence of "Loop" formation in the later phases of mastication suggests that such excursions were associated with finding and relocation of food particles on the occlusal table. Oftentimes such cycles were interrupted midway on the closing path by slight reopening of the jaw point, suggesting an attempt to relocate the food particles (Fig. No. 51). Masticatory cycles with "Point" form maximally open positions can be considered as primarily crushing and grinding cycles, while those with "Loop" forms can be classed as primarily food-finding and food-relocating cycles.

- e. The location of the paths of the closing strokes in relation to the C.V.A. in the frontal view was more or less evenly dispersed on the right and left sides. In the sagittal view nearly half the number of closing strokes passed anteriorly to the C.V.A., the rest either passing along the C.V.A. or posterior to it.
- f. Although in the frontal view a majority of the opening strokes passed closer than the closing strokes to the C.V.A., in the sagittal view a majority of the closing strokes passed posteriorly to the opening strokes.

- g. (i) In the particular Dentulous subject all the closing strokes terminated in open-mouth positions.
- (ii) Most of the points of termination of the closing strokes were concentrated on the C.V.A. medio-laterally as well as anteroposteriorly at varying vertical distances from the intercuspal position.

Although the Dentulous Subject chewed the food between the teeth on the right side, he performed some of the masticatory cycles entirely on the left side of the C.V.A., only the points of initiation and termination of the cycles being located on the C.V.A. (Fig. No. 50 2nd Phase)

Edentulous Subjects:- (Figs. No. 62 to 65 and Tables No. 40-46)

- a. (i) In the edentulous subjects the first opening stroke of every sequence started from the intercuspal position. Unlike the dentulous subject some of the subsequent opening strokes initiated from the intercuspal position and also from closed-mouth positions other than the intercuspal position.
- (ii) Most of the opening strokes initiated from open-mouth positions on the right side of C.V.A., a lesser number initiated from positions on the C.V.A. (in the frontal view) and a still lesser number from positions on the left side of C.V.A.
- (iii) In the sagittal view most of the opening strokes initiated from positions on the C.V.A., a lesser number from positions posterior to the C.V.A. and

a still lesser number from positions anterior to C.V.A.

- b. (i) Most of the opening strokes commenced on the right side, a lesser number on the left side and very few along the C.V.A. in the frontal view.
(ii) In the sagittal view about half of the opening strokes (51%) initiated on the anterior aspect, a lesser number (46%) on the posterior aspect and very few along the C.V.A.
- c. The maximally open position was generally located on the right side in the frontal view (in 72% of the cycles), and posterior to the C.V.A. in the sagittal view (in 81% of the cycles).
- d. Slightly more than half of the opening strokes terminated in "Loop" forms, the rest in "Point" positions.
- e. In the frontal view a majority of the closing strokes (62%) passed on the right side of the C.V.A., a smaller number passed on the left side and a still smaller number along the C.V.A.. In the sagittal view 81% of the closing strokes passed distally to the C.V.A.
- f. In most of the cycles viewed frontally the closing strokes passed closer to the C.V.A. than the opening strokes. In the sagittal view a very great number of closing strokes passed distally to the opening strokes.
- g. (i) Most of the closing strokes terminated in open-mouth positions, a lesser number terminated in closed-mouth positions and a still lesser number in intercuspal positions.
(ii) In the frontal view most of the closing strokes

terminated on the right side, some on the C.V.A. and a much lesser number on the left side.

- (iii) The points of termination in the sagittal view were more or less evenly dispersed on the C.V.A. anterior to the C.V.A. and posterior to the C.V.A.

2. Variations of the Positional Relationships of the Opening and Closing Strokes in Respect to the Three Phases of Mastication in the Dentulous and Edentulous Subjects:

a. Points of initiation of the opening strokes:
Dentulous Subject:

In the frontal view during the 1st Phase nearly half of the opening strokes initiated from open-mouth positions on the C.V.A. The number progressively increased as the mastication progressed through the 2nd and 3rd Phases. Some strokes also initiated from open-mouth positions on the non-preferred side and a few from positions on the preferred side.

In the sagittal view during the 1st and 2nd Phases more than 70% of the opening strokes initiated from open-mouth positions on the C.V.A. Some strokes also initiated from open-mouth positions posterior to the C.V.A. In the 3rd Phase all the strokes initiated from open-mouth positions on the C.V.A.

Edentulous Subjects:

- (i) During the 1st Phase nearly half of the opening strokes initiated from closed-mouth positions. The number progressively decreased in the 2nd and 3rd Phases.

(ii) In the frontal view during the 1st and 2nd Phases most of the opening strokes initiated from points on the C.V.A., while in the 3rd Phase a majority of strokes initiated from points on the preferred side.

(iii) In the sagittal view during the 1st Phase most of the opening strokes initiated from points on the C.V.A. The number of strokes initiating from points posterior to the C.V.A. increased in the 2nd Phase, and in the 3rd Phase most of the opening strokes initiated from points posterior to the C.V.A.

b. The Side of Initiation of the Opening Stroke:

Dentulous Subject:

In the frontal view during the 1st Phase, a majority of the opening strokes initiated on the non-preferred side, the number increased progressively in the later phases. Some strokes also initiated on the preferred side and this number also increased in the 3rd Phase.

In the sagittal view nearly half of the opening strokes initiated anteriorly to the C.V.A. in each of the three phases. The number of strokes initiating posterior to the C.V.A. showed a slight increase in the 3rd Phase.

Edentulous Subjects:

In the frontal view in each of the three phases a majority of the opening strokes initiated on the preferred side, the number being maximum in the 1st Phase.

In the sagittal view, during the 1st and 3rd Phases, nearly half the number of strokes initiated posterior to the C.V.A., while in the 2nd Phase, most of the opening strokes initiated anteriorly to the C.V.A.

c. Location of Maximally Open Position:

Dentulous Subject:

Whereas in the frontal view, during the 1st Phase, the distribution of maximally open positions on the preferred and non-preferred sides was nearly equal, in the 2nd and 3rd Phases most of the maximally open positions were located on the non-preferred side.

In the sagittal view although during the 1st and 3rd Phases, only a slightly greater number of maximally open positions were located anteriorly to the C.V.A., the number increased considerably in the 2nd Phase.

Edentulous Subjects:

In the frontal view, during the 1st Phase a maximum number of opening strokes terminated on the preferred side (80%).

In the sagittal view, during the 3rd Phase a maximum number of opening strokes terminated posterior to the C.V.A. (85%).

d. Form of Maximum Opening:

Dentulous Subject:

In the frontal view, the 3rd Phase showed maximum number of loop forms.

In the sagittal view, virtually all the maximum openings were point positions.

Edentulous Subjects:

In the frontal view during the 1st Phase, the incidence

of loop form at maximally open positions was the highest, it progressively decreased in the 2nd and 3rd Phases.

In the sagittal view, the incidence of loop forms was the lowest during the 2nd Phase.

e. Path of Closing Strokes in Relation to the C.V.A.:

Dentulous Subject:

During the 1st Phase, a majority of the closing strokes passed on the preferred side and posterior to the C.V.A.

During the 2nd Phase, a majority of the closing strokes passed on the non-preferred side and anterior to the C.V.A.

During the 3rd Phase, in the frontal view, a greater number of closing strokes passed either on the preferred side or along the C.V.A. than on the non-preferred side. In the sagittal view a greater number of closing strokes passed either posteriorly to the C.V.A. or along the C.V.A. than anteriorly to it.

Edentulous Subjects:

During the 1st Phase, a maximum number of closing strokes passed on the preferred side and posteriorly to the C.V.A. The number decreased in the 2nd Phase but increased again in the 3rd Phase.

f. Mutual Positional Relationship of the Opening and Closing Strokes to the C.V.A.:

Dentulous Subject:

During the 1st Phase, most of the opening strokes passed closer to the C.V.A. than the closing strokes but most

of the closing strokes passed posterior to the opening strokes.

During the 2nd Phase also most of the opening strokes passed closer to the C.V.A. than the closing strokes but the number of closing strokes passing posterior to the opening strokes and vice versa was equal.

During the 3rd Phase, a greater number of closing strokes passed closer to the C.V.A. than the opening strokes and most of the closing strokes passed posterior to the opening strokes.

Edentulous Subjects:

The number of closing strokes passing closer to the C.V.A. and posteriorly to the opening strokes increased progressively as the mastication progressed from the 1st to the 3rd Phase.

g. Points of Termination of the Closing Strokes:

Dentulous Subject:

During the 1st Phase most of the closing strokes terminated in open-mouth positions on the non-preferred side in the frontal view but on the C.V.A. in the sagittal view.

During the 2nd and 3rd Phases most the closing strokes terminated in open-mouth positions on the C.V.A. in both frontal and sagittal views.

Edentulous Subjects:

(i) During the 2nd Phase a comparatively higher number of closing strokes terminated in close-mouth positions

than in the 1st and 3rd Phases.

(ii) In the frontal view, a majority of the closing strokes terminated on the preferred side during the 1st Phase. During the 2nd Phase, a majority of strokes terminated on the C.V.A. During the 3rd Phase, a majority of the closing strokes terminated on the preferred side.

(iii) The incidence of the strokes terminating posteriorly to the C.V.A. was higher during the 1st Phase and lowest during the 2nd Phase.

3. Variations of Positional Relationships of the Opening and Closing Strokes Related to Variations of Consistency and Quantity of Food:

The condensed assessments are presented in the form of positional preference index.

4. Positional Preference Index:

Dentulous Subject:

The Total Masticatory Kinematic Performance P.P.I. of zero indicates that the Dentulous Subject 'A' performed the masticatory movements in a space evenly dispersed on the preferred and non-preferred sides anteriorly and posteriorly to the C.V.A. The P. P.I. value of +2 during the 1st and 3rd Phases of the masticatory sequences suggests a conservative tendency related possibly to the firmer consistency of food during the 1st Phase and a physiological demand for finer mastication of the food in the 3rd. Phase.

The negative P.P.I. during the "P.C. ad lib." exercise and "S.D.C. ad lib." exercise can be related to the

smaller size of the bolus. In both the instances the food was crushed during the first closing strokes which were executed in the preferred quadrant of the total envelope of movement space. (Figs. No. 50 and 57). During the "P.C. ad lib." due to the soft consistency of peanuts the subsequent masticatory cycles were performed more freely, hence the higher negative P.P.I. value of -10. The harder consistency of Sugar Drops and the occlusal jamming associated with these, required a comparatively greater control and hence the lesser negative P.P.I. value of -3 during "S.D.C. ad lib" exercise.

"P.C.F.M. ad lib" exercise represented a larger sized bolus which can be considered responsible for the higher positive P.P.I. value of +7 during the exercise. The +6 P.P.I. value during "M.C. ad lib" exercise reflects upon a greater demand on the masticatory apparatus both in terms of magnitude of the stresses involved and the style of mastication, i.e. the masticatory cycles showed a much greater opening of the mouth compared to other exercises.

Thus the kinematic performance in the Dentulous Subject 'A' showed conservative tendency in respect to the larger size of the bolus and tougher consistency of food. A smaller-sized bolus was chewed more freely. The performance during the 1st and 3rd Phases of mastication was more conservative compared to the 2nd Phase.

Edentulous Subjects:

The Total Masticatory Kinematic Performance P.P.I. in the Total Edentulous Sample showed a positive value of +12 indicating that the functional movement space was

and the C.V.A.

The Total Masticatory Kinematic Performance P.P.I. during the three phases of the total masticatory performance in the edentulous subjects showed a more conservative performance during the 1st and 3rd Phases than during the similar characteristics during the three phases. The total edentulous sample performance of individual exercises also showed similar characteristics.

As in the dentulous subject, the full-mouth peanut chewing exercise in the edentulous subjects showed the most conservative performance with a P.P.I. of +15. The performance was more conservative during the 1st Phase reaching a P.P.I. of +17.

The "P.C. ad lib." and "M.C. ad lib." exercises showed comparatively higher positive P.P.I. values of +13 and +17 respectively during the 3rd Phases of the masticatory sequences.

During "S.D.C. ad lib." exercise the performance was more conservative in the 1st Phase than in the 3rd Phase.

In all the exercises the P.P.I. values were more conservative in the edentulous subjects than in the dentulous subject.

II. The Role of Cuspal Guidance During Mastication in the Dentulous and Edentulous Subjects. (Tables No. 38, 39 and 78 and 89.)

The incidence and types of cuspal guidance were determined by comparing the outline forms of the occlusal parts of the masticatory cycles to the total envelope of movement space in the individual subjects.

1. The Incidence of Cuspal Guidance:

The incidence of cuspal guidance in the total edentulous sample was much higher than in the dentulous subject. Considered alone this did not appear to be of any great significance and could be interpreted as an individual variation. A detailed examination on the other hand suggested a difference in the pattern in the two types of subjects. In the dentulous subject cuspal guidance was generally associated with either the opening or the closing strokes of a cycle. In the edentulous subjects in a majority of the cycles showing cuspal guidance, the influence could be seen in both the opening and closing strokes of the same cycle. In some cycles cuspal guidance occurred in both the frontal and sagittal views of both the opening as well as closing strokes of the same cycle.

Whereas the higher incidence of cuspal guidance in the edentulous subjects may be due to a more balanced occlusion in the artificial dentures than in the natural dentition, the incidence of cuspal guidance can also be interpreted as a quantitative expression of mastication governed by the subject performing the mastication and also the quality of bolus being masticated. Thus the higher incidence of cuspal guidance in the edentulous state can also be related to a greater quantitative demand for mastication by the edentulous masticatory and digestive systems. The higher positive P.P.I. of masticatory kinematic performance in the edentulous subjects compared to the dentulous also supports the above contention.

The lower incidence of cuspal guidance in the edentulous subject 'D' can be attributed to poorer stress bearing quality of the denture bearing area. The subject complained of tenderness of the lower alveolar ridge at the end of the experiment and possibly was not able to give his "normal" performance during the exercises.

2. Variations of Incidence of Cuspal Guidance during the Three Phases of Mastication:

In the dentulous subject the incidence was highest during the 1st Phase, low during the 3rd Phase and least in the 2nd Phase. During the 2nd Phase cuspal guidance was associated only with the closing strokes.

In the edentulous subjects the overall incidence of cuspal guidance increased progressively as mastication progressed. During the 2nd Phase a greater number of masticatory cycles showed cuspal guidance during both the opening and closing strokes than in the other two phases.

3. Types of Cuspal Guidance:

Depending upon the manner of occlusal contact and the subsequent movement following the occlusal contact, the cuspal guidance can be classified as:

(i) Point Reflective Cuspal Guidance:

The closing stroke terminated in an eccentric inter-occlusal contact and without any intercuspal sliding, the next opening stroke initiated from the same eccentric contact. This Point Reflective cuspal guidance essentially occurred between closing and opening strokes. The closing stroke preceding the point reflective cuspal guidance formed an acute angle with the opening stroke that followed.

(ii) Sliding Deflective Cuspal Guidance:

The opposing teeth contacted in an eccentric inter-occlusal relation during an opening or closing stroke. The cusps slid against one another and resulted in an opening or closing movement of the jaw point along a border path for some distance. This type of cuspal guidance occurred during an opening or closing stroke, and changed the direction of motion of the jaw point generally through an obtuse angle.

Whereas point cuspal guidance marked the termination of one masticatory cycle and initiation of the next, the sliding cuspal guidance formed a part of the opening or closing strokes but at times was also shared by two consecutive cycles in that the sliding contact formed the terminal part of one closing stroke and then continued to form the initial part of the next opening stroke.

Both types of cuspal guidance could be seen in both the frontal and the sagittal views. In the frontal view the sliding cuspal guidance when occurring during an opening stroke involved a movement from the medial to a lateral direction and when occurring in a closing stroke showed a movement from the lateral to a medial direction. In the sagittal view on the other hand sliding cuspal guidance could produce movements from anterior to posterior or reverse during both opening as well as closing strokes. The incidence of protrusive cuspal guidance during closing strokes appeared only in the edentulous subjects. In the dentulous subject only retrusive cuspal guidance was seen during the closing strokes in the sagittal view.

The two types of cuspal guidance suggest two different functions during mastication. The point cuspal guidance acted very similar to a hammer that has struck a blow at a point and rebounded from this point, thus exercising a crushing or penetrating action. On the other hand, sliding cuspal guidance displayed a shearing or shredding action. The opposing cusps engaged the food and movements of the lower jaw in a horizontal plane towards or away from the intercuspal position helped to shear or tear the food fibres apart.

It can be visualised that both these types of movements i.e. crushing and penetrating resulting in point cuspal guidance and shearing and tearing resulting in sliding cuspal guidance are possible even without actual contact between the teeth. Intercuspal contact seemed to occur when either the size of bolus was very small or the

bolus had been sufficiently softened to allow complete penetration of the food by the cusps. This is evident from the higher incidence of cuspal guidance during P.C. ad lib. exercise and the progressive increase of cuspal guidance as the mastication progressed through the three phases.

Generally masticatory cycles terminating in point reflective cuspal guidance can be expected to produce:-

- (i) Crushing of soft brittle and hard foods as peanuts and sugar drops by the vertical strokes.
- (ii) Tenderisation or softening of firm and tough foods like meat by the hammer strokes.
- (iii) A pumping action on the occlusal surfaces to dislodge the food particles jamming the occlusal surfaces from previous crushing strokes, when the bolus is large.

The masticatory cycles showing sliding cuspal guidance can be expected to produce:

- (i) Finer pulverisation of such foods as Peanuts and Sugar Drops (grinding action).
- (ii) A tearing and teasing of such fibrous foods as meat (shreading action).
- (iii) Due to a marked horizontal component of motion such cycles can be expected to dislodge the jammed food particles and clear the occlusal surfaces.

4. Variations of cuspal guidance in respect to variations of food consistencies (Tables No. 38, 39, 82 to 89):-

In both the dentulous and edentulous subjects there was some similarity in the general pattern of influence of cuspal guidance in relation to food consistencies. The features of the individual exercises can be summed up as under:-

1. "P.C. ad lib." exercise:

The incidence of cuspal guidance was highest in this

exercise for both the dentulous and edentulous subjects. In the dentulous subject in most of the cycles cuspal guidance occurred either in the opening or the closing strokes. In very few cycles did cuspal guidance occur in both strokes of the same cycle.

In the edentulous subjects in most of the cycles cuspal guidance occurred in both the opening and closing strokes of the same cycle. The incidence of cuspal guidance increased as the mastication progressed through the three phases. During the 2nd Phase a maximum number of cycles showed cuspal guidance in both the opening and closing strokes.

In the total performance of the exercise in both the dentulous and edentulous subjects, the incidence of sliding cuspal guidance was higher than the point cuspal guidance, the difference being more pronounced in the dentulous subject than in the edentulous sample. In the edentulous subjects the incidence of point cuspal guidance progressively increased and was seen in a majority of the cycles in the 3rd Phase. There was a corresponding decrease in the occurrence of sliding cuspal guidance as the mastication progressed.

2. "P.C.F.M. ad lib" exercise:

In both the dentulous and edentulous subjects the incidence of cuspal guidance during this exercise was lower than "P.C. ad lib" and "M.C. ad lib." exercises and higher than the "S.D.C. ad lib." exercise.

In the dentulous subject cuspal guidance was associated only with the opening stroke. In the edentulous subjects the number of cycles showing cuspal guidance only in the opening strokes was higher than in other exercises. Similarly

the number of cycles showing cuspal guidance only in the closing strokes was also higher than in other exercises. Although most of the cycles showed cuspal guidance in both opening and closing strokes of the same cycle the incidence of such cycles was much lower compared to other exercises.

The total performance of P.C.F.M. ad lib. exercises showed a predominance of sliding cuspal guidance. Both the point cuspal guidance as well as the sliding cuspal guidance showed a progressive increase in incidence during the three phases of mastication.

3. "M.C. ad lib." exercise:-

In both the dentulous as well as the edentulous subjects the incidence of cuspal guidance during the exercise was second highest. In the dentulous subject there was a similar number of cycles showing cuspal guidance in only opening or closing strokes.

In the edentulous subject on the other hand the maximal number of cycles showed cuspal guidance during both the opening and closing strokes. The incidence of cycles showing cuspal guidance in only the opening or closing strokes was much lower than in other exercises. In the 1st Phase the incidence of point and sliding cuspal guidance was almost similar being 30% and 32% respectively. During the 2nd and 3rd Phases the incidence of sliding cuspal guidance was much higher than point cuspal guidance.

4. "S.D.C. ad lib." exercise:-

Whereas the dentulous subject throughout the exercise did not give any evidence of inter-occlusal contact, the edentulous subjects showed a cuspal guidance incidence of

60%. This was lowest in the entire edentulous performance. Again most of the cuspal guidance was seen in both opening and closing strokes of the same cycle. The number of opening strokes showing cuspal guidance was higher than the closing strokes.

During the 1st Phase the incidence of point and sliding cuspal guidance was similar but in the 2nd and 3rd Phases the point cuspal guidance formed the dominant feature. The incidence of sliding cuspal guidance during the exercise and during the 2nd Phase was the lowest of the entire experiment.

The role of cuspal guidance in the edentulous subjects in comparison to the dentulous subject can be summed up as being contributory to the "Conservative" kinematic masticatory performance during the edentulous state, the term "Conservative" implying a cautious performance intended for preservation of the masticatory apparatus (including prevention of displacement of the dentures) and also the digestive system as a whole. The greater number of masticatory cycles in the exercises performed by the edentulous subjects, the higher positive P.P.I. during the edentulous performance and the greater incidence and involvement of cuspal guidance in masticatory cycles are all suggestive of a greater care and effort on the part of edentulous subjects in the preparation of a similar quality and quantity of food for swallowing than by the dentulous subject. Whether this extra effort resulted in a finer comminution of food thereby indicating a greater proficiency of the artificial dentures or was a compensation for the loss of efficiency due to loss of teeth cannot be established.

III. Envelope of Movement Space used during Mastication of
Different Foods:- (Figs. No. 60, 61 and 66 to 74. Tables No. 90
to 92)

1. General characteristics:

- a. In the dentulous subject in some of the exercises there appeared to be a tendency for the different phases of the exercise to be performed in selected quarters of the total envelope of movement space. Although during P.C. ad lib. and M.C. ad lib. exercises the 1st Phases were performed on the right side and posterior to C.V.A., the 2nd Phases a little further anteriorly and the 3rd Phases still further anteriorly, no definite pattern could be established because in other exercises the arrangements were all reversed or different. In the edentulous subjects, most of the space used during the three phases was located on the right side and posteriorly to the C.V.A. Only in one subject there was a tendency to perform anteriorly to the C.V.A.

In the dentulous subject the envelopes of movement generally presented smoother and more contained outline forms than in the edentulous subjects. In the edentulous subjects the outline forms tended to become smoother in the 2nd and 3rd Phases of masticatory sequences. In both the dentulous as well as the edentulous subjects the smoothest outlines of the envelope of movement space were used during the M.C. ad lib. exercise. This appears to be related to the compact form the meat bolus maintained throughout the sequence,

thus reducing the number of food-finding excursions during the performance. The comparatively greater lateral deviations in the edentulous state may also be attributed to the impaired proprioception. Some of this is lost with the loss of teeth and some of it is masked by the coverage by the dentures. Thus the bolus of food cannot be controlled as efficiently as in the dentulous state and the "food-finding" movements appear exaggerated.

- b. The vertical dimension of the envelope of movement space used during mastication in the dentulous subjects was twice as great as in the edentulous subjects. In both the dentulous as well as edentulous subjects there does not appear to be any relationship between (i) the size of the food bolus, (ii) the phase of the masticatory sequence, and (iii) the extent of mouth opening during mastication. On the other hand the consistency of the food bolus appears to have some influence on the degree of mouth opening. In both the dentulous as well as edentulous subjects maximal mouth opening was seen during M.C. ad lib. and S.D.C. ad lib. exercises. In the former exercise the opening increased as the mastication progressed while in the latter the opening decreased with the advancement of mastication; the increasing or decreasing vertical dimension of the cycle providing an increasing or decreasing momentum to the closing stroke as the need varied.
(Figs. No. 70 to 74)

2. Location of the intercuspal position in relation to the Envelope of Movement Space used during ad lib. mastication:-

In the dentulous subject, with the exception of the first cycle in every sequence, all subsequent cycles initiated from open mouth positions and terminated in open mouth positions, the average vertical distance between the terminal point of the cycles and the intercuspal position being 0.72 mm.

In the edentulous subjects on the other hand 39.5% of the cycles terminated in closed mouth positions and 60.3% in open mouth positions. The average vertical distance from intercuspal position to the terminal point of the cycle in the edentulous sample was calculated as 1.03 mm. There were considerable variations in individual subjects. In subject 'B' the terminal point of the cycle was located at an average distance of 0.03 mm. from intercuspal position, while in subject 'D' the average distance was measured as 2.32 mm. As indicated earlier subject 'D' presented a poorer mucoperiosteal support for the dentures and complained of slight tenderness of the ridges at the end of the experiment. The increased vertical distance between the terminal point of the masticatory cycle and the intercuspal position in the particular circumstances suggests that the subject was not exercising full closure of the mouth due to tenderness of the ridges. (It would be interesting to examine the behaviour of elevator and depressor muscles of the jaw in this subject.)

In the dentulous subject, in 48% of the cycles

at a vertical distance of 0.55 mm. from the intercuspal position the terminal points of the masticatory cycles were located directly on the C.V.A. both in the frontal as well as sagittal views, i.e. directly below the intercuspal position. As the vertical distance increased the cycles terminated on the right and left side of the C.V.A. At a distance of 1.8 mm. from the intercuspal position the masticatory cycles terminated on the left side and also posteriorly to the C.V.A. This indicates that in the dentulous subject examined the points of initiation and termination of the masticatory cycles were generally confined to the intercuspal position though separated from it by the intervening food.

On the other hand in the edentulous subjects the masticatory cycles could terminate in the closed mouth position at the same vertical level as the intercuspal position but horizontally at some distance from it mediolaterally as well as anteroposteriorly. The average distances in the edentulous sample were 1.63 mm. on the right side, 0.5 mm. on the left side, 0.18 mm. anterior and 0.6 mm. posterior to the C.V.A. This indicates that whereas in the dentulous subject the occlusal end of the envelope of movement space is a point position terminating in intercuspal position, in the edentulous state it resembles a surface that extends for some distance on all sides of the intercuspal position.

SECTION VIII

GENERAL DISCUSSION

GENERAL DISCUSSION

The differences between the masticatory function in the Dentulous and Edentulous States can be fully appreciated only after considering the fundamental differences between the masticatory apparatus in the two states. Some of the differences relevant to this investigation are:-

1. The most evident difference is that in the dentulous state the occlusal tables form an integral part of the masticatory apparatus, while in the edentulous state the artificial dentures merely rest upon the alveolar processes and are easily dislodged. This creates an extra problem for the edentulous neuromuscular mechanisms. The edentulous subject performs mastication with a constant conscious or subconscious awareness of his limitations. He has to adjust and modify his reflexes so as to perform masticatory function without displacement of the dentures.
2. The edentulous subject with the loss of teeth also loses the fine proprioceptive system based within the periodontal membrane. Furthermore a wide sensory area of the oral cavity is covered by the dentures and the sensory receptor organs dispersed in the mucoperiosteum in this area become relatively inoperative. Thus the edentulous subject has a comparatively impaired neuromuscular mechanism.
3. The edentulous state is generally associated with ageing and accompanied atrophic changes. These changes involve all parts of the masticatory apparatus and develop gradually after the loss of teeth. The changes have a tendency to stabilize after some time.

These differences create mechanical, biological and also emotional problems for the edentulous subject. His achievement in Masticatory Kinematic Performance depends upon how amicably he can adjust himself to these handicaps. It is but natural that there should be a transitional

stage, a period during which the changes stabilize and the subject acquires the necessary skill for using the dentures. Because of the possible variability of performance during this transitional period, the subjects selected for this investigation were required to have a complete denture experience of more than five years, so that the kinematic and other characteristics of edentulous subjects examined belonged to the age bracket of 60 - 70 years.

For a comparative examination of the dentulous state an 18 year old male was selected. He had a full complement of natural teeth, a good arch-form, good intercuspation and no history of any T.M.J. conditions.

The extreme difference in age between the dentulous and edentulous subjects was expected to magnify the possible differences between the two states of the masticatory apparatus.

METHODS EMPLOYED:

1. CONSTRUCTION OF COMPLETE DENTURES:

An intra-oral central-bearing gothic-arch tracing technique was used for recording the maxillomandibular relationship for the dentures. The selection of the particular method was based upon the contention by Posselt ⁽³⁸⁾ that the maximally retruded functional position of the mandible is located at the apex of the arrow point tracing and also upon the assumption that as there was only a single centrally-located point of contact between the opposing jaws during registration whatever relationship the mandible acquired in respect to the maxilla in the different edentulous subjects, it would be free from such individual variations of technical origin which could result from uneven contact between the wax rims. This problem was also encountered by Sheppard and Sheppard ⁽⁴⁹⁾ and resolved in the above manner.

Particular efforts were made to locate the intercuspal position of the artificial dentures at the apex of the gothic arch tracing, the objective being establishment of a reference point that could be considered common at least for all the edentulous subjects.

The subjects took two to eight weeks to become accustomed to the new dentures, the time determining factors being satisfaction of the subject in respect to comfort and performance and also absence of any clinical manifestations of trauma or mal-performance particularly sliding movements of the dentures during closure into intercuspal position.

2. PHOTO-ELECTRIC MANDIBULOGRAPHY:

The major deterrent to research in the field of Kinematics of Masticatory Function in the edentulous state as expressed by Kurth⁽³¹⁾ has been the easy dislodgement of the dentures by the heavy and cumbersome face-bows and motion analysers attached to the lower denture. The equipment used by Gibbs et al⁽¹⁶⁾ in their investigation had moving parts weighing as much as 60 gms. In the equipment used for the present investigation the only moving part was the Mandibular Light Assembly, which for the dentulous subject weighed 8.0 gms. and was even lighter (6.0 gms.) for the edentulous subjects. The light assembly did not appear to cause any displacement of the dentures or interference to the functional movements.

Movement of the head during mastication caused no artefacts in the recorded jaw point movements because the photocell frame was securely anchored to the head and moved with it during average normal activity, however sudden vigorous head movements had to be avoided to prevent an independent swinging of the photocell frame. These movements were not associated with mastication and occurred only when the subject changed his posture in the chair or performed other similar actions. During the recording the subject was requested to avoid such

movements as much as possible.

The high degree of linearity in the movements monitored by the photoelectric mandibulograph made this system most suitable for monitoring the masticatory and other movements of the jaw point. The 100% linearity along the Z axis facilitated an accurate assessment of the antero-posterior excursions of the jaw point at the points of initiation and termination of the masticatory cycles.

Although masticatory movements could be photographed from the oscilloscope screen, hand sketching was preferred because individual cycles could be examined without any overlapping. This also minimised the cost of the experiment.

3. THE POINTS AND AXES OF REFERENCE:

The coronal, horizontal and sagittal planes as suggested by Brill et al. ⁽¹²⁾ were interpreted as X, Y and Z axes respectively, intersecting each other at the intercuspal position.

The distance along the X axis indicated the vertical distance from the intercuspal position. Distances along the Y axis indicated measurements in the right/left directions from the intercuspal position. Similarly measurements along the Z axis represented distances in the anterior/posterior direction from the intercuspal position.

The X axis has also been referred to as the Central Vertical Axis (C.V.A.) At the inter-occlusal level it represented the intercuspal position in both frontal and sagittal views. At levels below intercuspal position in the frontal view the C.V.A. represented the median plane, while in the sagittal view it aligned with the coronal plane. This made possible the exact location of the paths and positions of the jaw point in respect to the intercuspal position and the horizontal of the base of the skull.

The C.V.A. has also been used to arbitrarily divide the envelope of total jaw point movement space into four quadrants by extension of Y and Z axes as planes radiating from the C.V.A. Thus the space used by a single masticatory cycle, a sequence or the total performance by one or more subjects could be compared to the total envelope of movement space for one or more subjects. The method achieves all the objectives of the Hildebrand technique⁽²⁰⁾, and avoids exposure of the subject to X-ray radiation. Hildebrand compared the antero-posterior disposition of the opening and closing strokes to an arc with the centre at the crest of the head of the condyle. The arc was as arbitrary as the sagittal view of the C.V.A. used in the present investigation for the antero-posterior assessment.

4. RECORDING OF THE BORDER MOVEMENT PATHS AND POSITIONS:

Both dentulous as well as edentulous subjects experienced difficulty in performing the border excursions. Outside assistance evoked muscular resistance and did not always assure border movements. Similar difficulties have been expressed by Nemoto et al.⁽³⁵⁾ The exercises were designed to overlap one another and the accuracy of location of border paths and positions was confirmed from repeat performances of the same and also overlapping exercises. Outside assistance was used only during the recording of maximally retruded paths and positions.

5. DENTURE BASE MOVEMENTS DUE TO RESILIENCE OF SOFT TISSUES:

Sheppard and Sheppard in their observations on swallowing positions in edentulous subjects⁽⁴⁹⁾, drew attention to denture base movements on the alveolar ridges due to compression and displacement of soft tissues. Although these have been referred to as denture base movements, these can be expressed more accurately as independent jaw movements inside the fitting surfaces of the dentures, particularly the lower denture. The movements of the lower denture synchronously

with the movements of the mandible are prevented due to intercuspal engagement of the lower denture with the upper denture. A jaw movement of an amplitude greater than the compressibility of the soft tissues would be required to move the lower denture and the mandibular light attached to it during the functional and other movements. Thus the movements as monitored by the mandibular light assembly may possibly be smaller than the actual jaw movements. Likewise forces of average magnitude resulting in vertical compression of the soft tissues as during a clench before swallowing did not produce any shifting of the mandibular light assembly. The downward movement of the lower denture was counteracted by an upward movement of the upper denture and the position of the mandibular light remained constant. Thus during normal functional performance the possible "denture movements" did not produce any significant effects.

ENVELOPE OF TOTAL MOVEMENT SPACE IN THE DENTULOUS AND EDENTULOUS SUBJECTS:

The general shape and form of the envelope of total jaw point motion in the edentulous subjects was very similar to that in the dentulous subject and conformed with descriptions presented by Posselt (38, 39), Schweitzer (43, 44), Nemoto et al. (35), and others (6, 30, 52).

In both types of subjects the envelope was generally rhomboidal in cross-section and inverted pyramidal in form. The rhomboidal base of the pyramid represented the occlusal or the superior boundary of the envelope and the pointed apex the maximally open position.

In both dentulous and edentulous subjects the envelope of movement space appeared to be rotated around a vertical axis towards the right side which in the four subjects examined was also the preferred side

for mastication. This axial rotation of the envelope to the right side was due to (i) the retruded lateral excursion path on the right side being located farther posteriorly than on the left side, and (ii) the retruded lateral excursion on the left side extending farther out laterally and anteriorly than on the right side. Thus the width of the lateral acute angles on the right side was greater than on the left side.

As these observations were made at the level of the occlusal end of the envelope which was described by movements of the jaw point in a horizontal plane with maintained tooth contact, it can be deduced that at the occlusal level, whereas on the right or preferred side the jaw point has a greater capacity for distal excursion, on the left side or non-preferred side it has a greater capacity for lateral excursion.

Although the authors have not commented, the above three observations, i.e. (i) rotation of the envelope to the right side, (ii) a greater capacity for distal excursion on the right side and (iii) a greater capacity for lateral excursion on the left side, can be observed in the illustrations by Posselt (38), Schweitzer (43, 44) and Nemoto et al. (35).

THE POINTS OF DIFFERENCE IN THE DENTULOUS AND EDENTULOUS ENVELOPES OF TOTAL MOVEMENT SPACE:

The envelope of total movement space in the edentulous subjects is generally smaller than the dentulous envelope in all dimensions. The envelopes also differ from one another in the location and form of the retruded border movement paths both at the occlusal level and also during opening and closing movements.

In the dentulous subject although unrestrained lateral and open/close movements initiated from and terminated in the intercuspal

position, the jaw point could be moved 0.5 mm. further distally to the intercuspal position by the application of posterior traction. With the mouth closed this maximally retruded position was located directly on the Z axis. From this maximally retruded position the subject could perform the maximally retruded open/close movements, but the right/left component in these movements became zero while the teeth were still some distance apart. The dentulous subject could not perform any lateral movements from this maximally retruded position. The jaw point had to move forward to the intercuspal position before any lateral excursions could initiate. Furthermore all sliding contact retruded lateral excursions viewed in the horizontal plane, passed either along the Y axis or anteriorly to it. In no instance in the dentulous subject did the movements pass distally to the Y axis or the intercuspal position. Thus in the dentulous subject examined, the intercuspal position was the maximally retruded functional position. Although the jaw point could be forced in a further distal position only open/close movements could be performed from this position.

In the edentulous subjects it was evident from the gothic arch tracings that the sliding contact lateral excursions without posterior traction initiated from and terminated in intercuspal position. With posterior traction the jaw point could be shifted up to 0.8 mm. distal to the intercuspal position on the Z axis. The retruded sliding contact lateral excursions could initiate unassisted from this maximally retruded position but were accompanied by a downward displacement of the jaw point due to intercuspal engagement. These sliding contact lateral excursion paths passed distally to the Y axis and approached the maximally retruded position even from a posterolateral direction, thus giving the posterior superior boundary of the envelope a cleft appearance in the horizontal view. In the edentulous subjects intercuspal position although being located at the apex of the gothic arch tracing was not

the maximally retruded functional position, the jaw point could perform unassisted lateral excursions from points located further distally.

The maximally retruded open/close movement path in the dentulous subject was very similar in form to the paths recorded by Posselt ⁽³⁸⁾, Schweitzer ^(43,44), Knap et al. ⁽³⁰⁾ and Nemoto et al. ⁽³⁵⁾. The path was broken in the middle by an obtuse angle indicating the point of compulsory protrusive translation of the condyles. ⁽³⁸⁾ In the edentulous subjects on the other hand the paths were more or less continuous and this obtuse angle was not noticeable. The paths resembled very closely to those recorded by Posselt ⁽³⁸⁾ in a postmortem preparation after resection of the temporomandibular ligaments, and by Woelfel et al. ⁽⁶⁴⁾ in live edentulous subjects.

It is possible that differences in the form of the posterior boundaries of the envelopes of movement space in the edentulous subjects compared to the dentulous may be related to laxness of the temporomandibular and other ligaments of the masticatory apparatus resulting from the loss of teeth either as an atrophic consequence and/or as an adjustment to compensate for the disruption of the integrated state of the masticatory apparatus following the loss of teeth. This can also be interpreted to support the hypothesis by Atwood that the distal border positions and paths of the mandible are maintained by muscles with ligaments in reserve. In the edentulous state when ligaments weaken the mandible can move further distally than in the dentulous state when the ligaments are strong. ⁽¹³⁾

SIMULATED CHEWING MOVEMENTS IN THE DENTULOUS AND EDENTULOUS SUBJECTS.

Simulated chewing movements were examined primarily with the object of establishing a method of assessment for the masticatory movements.

Simulated ad lib. movements represented the habitual performance while movements on the right and left sides were considered controlled performance.

All the subjects examined preferred right side for chewing. When asked to "pretend chewing as they pleased" the subjects performed the act on the right side, but the pattern of movements was quite different from that when they were instructed to perform the exercise on the right side.

In the dentulous subject during ad lib. performance the movements initiated from and terminated in the intercuspal position and followed a smooth cyclic pattern in a clockwise direction. The cuspal guidance occurred in relation to the opening strokes. The envelope of movement space used during this exercise was narrow and well contained. During performance on the right side with the exception of the points of initiation and termination of the cycles which were at the intercuspal position, there were differences in the positional relationships of the opening and closing strokes, the role of cuspal guidance and the envelope of movement space used. The opening strokes initiated on the right side and also on the left side, maximal opening was reached on the right side and also on the left side. Similarly cuspal guidance occurred in the opening or in the closing strokes or even in both, and in the frontal, sagittal or both views. All these differences were due to only a verbal designation of the side, indicating how easily the neuromuscular patterns for these movements could be altered. The neuromuscular mechanism appears to become confused between the external directives such as instructions during performance and reflex directives originating from the proprioceptive systems in the masticatory apparatus and produces the confused patterns of performance, making attribution of a particular function to these and also the masticatory movements, difficult.

Simulated chewing movements in the dentulous and edentulous subjects differ in the following:-

1. The ad lib. movements were generally performed with a greater ease and control by the subjects, much more so by the dentulous than by the edentulous.
2. In the dentulous subject all simulated movements initiated from and terminated in the intercuspal position. In the edentulous subjects the ad lib. movements initiated from and terminated in either intercuspal position or positions located distal to it. The points of initiation and termination of the simulated chewing movements on the right and left sides showed a much wider dispersion including even open-mouth positions.
3. In the dentulous subject although during ad lib. movements the closing strokes passed on the right side or the preferred side and closer to the C.V.A. than the opening strokes in the frontal view, in the sagittal view the cycles were executed anteriorly to the C.V.A. virtually in their entire course. This conforms with the observations by Schweitzer (43, 44). There was a consistent protrusive component in the movements which changed into a retrusive component only in the terminal parts of the closing strokes. As the movements were monitored at the incisal point, a protrusion of the point indicated a translatory protrusive excursion of the mandible as a whole. Both the condyles and the incisal point moved in a forward and downward direction. Similarly a retraction of the incisal point during closure indicated a translatory retrusion of the mandible from a protruded position, but a persistence of protrusive component during closure as observed in the dentulous subject could only be interpreted as a hinge movement around a transverse axis located in the region of the condyles which may be stationary in a protruded position or returning slowly

towards the closed-mouth position, the return movement becoming entirely translatable in the terminal parts of the closing stroke.

The simulated chewing movements particularly on designated sides, involved varying degrees of lateral components. These lateral components, translatable protrusive or retrusive components and the open close components all manifested themselves simultaneously indicating that performance of lateral movements did not necessarily depend upon a fixation of the working side condyle. Such movements could also take place by a slower protrusive or retrusive translatable movements of the working side condyle possibly assisted by the lateral translatable or Bennett movements. This contrary to observations by Gibbs et al. ⁽¹⁶⁾ only to the extent that whereas they indicate that in the terminal part of the functional movements "the working side condyle is nearly stationary only in the sagittal view...", the present investigation suggests that varying degrees of translatable movements of the working side condyle are possible from the initiation to the termination of the cycles. This is further supported by the observation that in the different cycles in both frontal and sagittal views the directions of the paths of initiation of the opening strokes and termination of the closing strokes differed considerably and were changing continuously. If the working side condyle was stationary these directions would be constant in all cycles.

In the edentulous subjects during ad lib. performance there was a strong tendency for the cycles to be executed on the preferred side, and posterior to the C.V.A. In most of the cycles the opening stroke from its initiation passed in a distal and downward direction and the closing in a forward and upward direction. Whereas the protrusive component in the opening stroke in the dentulous subject indicated translatable protrusion

of the jaw, the retrusive component in the opening stroke in the edentulous subjects only indicated that the movements were executed closer to the posterior border of the total envelope of movement space. This does not negate the possibility of protrusive translation of the mandible during these movements.

Similar to the dentulous subject the edentulous simulated chewing movements showed varying degrees of lateral components. The greater capacity for distal excursion in the edentulous envelope of total movement space is suggestive of a rotation of the mandible around a vertical axis located somewhere on the medial aspect of the working side condyle during these movements. This would result in a retrusive movement of the working side condyle and a protrusive excursion of the balancing side condyle. In the edentulous subjects many of the simulated chewing cycles initiated from and terminated in positions distal to the intercuspal position, particularly during the performances on the designated sides. In the frontal view the closing strokes showed a tendency to be located on the designated side, but in the sagittal view passed distally to the C.V.A. In the dentulous subject the closing strokes passed anteriorly to the C.V.A.

4. The amplitude of movements in the dentulous subjects was much greater than in the edentulous subjects.
5. Although in the above text the terms "working side" and "balancing side" have been used, these are only meant to express the conventionally accepted situations of maxillomandibular dental arch relationships and directions of motion. These only have a didactic significance. The simulated and even masticatory movements do not necessarily

conform to the definitions generally given for these two terms. Conventionally the working side condyle is supposed to remain stationary while the balancing side condyle moves downward and forward (38, 39). In actual occurrence the movements do not rigidly conform to any such pattern, the subjects could bring the teeth together in chewing contact on the right side with the right condyle moving downward and forward and the left condyle performing as the "working side" condyle. The movements could also follow the conventional pattern. Gibbs et al. (16) have adopted their own definition of working side. According to them the incisal point moves from the side of the food to the opposite side, which is reverse of the definition used by Posselt (38, 39). As indicated earlier these terms are only of didactic interest and have no clinical significance.

MASTICATORY MOVEMENTS IN THE DENTULOUS AND EDENTULOUS SUBJECTS.

I. POSITIONAL RELATIONSHIP OF THE OPENING AND CLOSING STROKES:

Points of initiation and termination of simulated chewing and Masticatory Movements:

Whereas in the dentulous subject the masticatory cycles initiated from and terminated in positions located on the C.V.A. directly below the intercuspal position, and varied only in respect to the vertical distance of these positions from the intercuspal position due to the varying thicknesses of food between the teeth, in the edentulous subjects the masticatory cycles initiated from and terminated in positions dispersed around the intercuspal position at the inter-occlusal level and also in open-mouth positions. In almost half of the masticatory cycles in the total edentulous performance these positions were located further distally to the inter-cuspal position at the inter-occlusal level and also in open mouth positions. Intercuspal position in the artificial dentures represented the apex of the gothic arch tracing.

According to Posselt (38, 39) the apex of the gothic arch tracing represents the maximally retruded functional position. He made this observation on dentulous subjects, and is supported by many other investigators (6, 9, 21, 22, 30, 35, 43,) (44, 63). Observations in the dentulous subject during this investigation also confirm Posselt's findings, but differ considerably from those in the edentulous subjects.

Silverman (56) contends that in the edentulous subjects the "Biting point" -- maxillomandibular relationship acquired during rapid unassisted tapping movement of the mandible against the maxilla --, may be located anteriorly or even

further posteriorly to the apex of the gothic arch tracing.

Sheppard and Sheppard ⁽⁴⁹⁾ observed anteroposterior and posteroanterior sliding movements in the terminal parts of the masticatory cycles in edentulous subjects but did not examine their relationship to the apex of the gothic arch tracing. In this respect observations during this investigation revealed that :-

- (i) The apex of the gothic arch tracing in the edentulous subjects was a functional position but not the maximally retruded functional position.
- (ii) Masticatory cycles in the edentulous subjects initiated from and terminated in positions further distal to the apex of the gothic arch tracing.
- (iii) These retruded functional positions could be located on the Z axis distal to the intercuspal position and also on the right and left sides at the inter-occlusal level.
- (iv) Considering the outline form of the occlusal end of the envelope of total movement space in the edentulous subjects as recorded during this investigation, the dispersion of the points of initiation and termination of the masticatory cycles around the intercuspal position appears quite feasible.
- (v) During the 1st Phase of the masticatory sequence when the bolus had the firmest consistency, the majority of the masticatory cycles initiated from and terminated in positions distal to the intercuspal position, indicating the objective behind the distal location of these positions. This phenomenon in the edentulous state of masticatory apparatus appears to be very similar to some of the survival and homoeostasis phenomena observed by Hildebrand ⁽²⁰⁾, Sheppard ⁽⁵⁰⁾, Brill et al. ⁽¹²⁾ and Seitlin ⁽⁶⁹⁾.

Hildebrand (20) found that a particular side was preferred for mastication because it offered better conditions of articulation of teeth and facilitated smooth intercuspal gliding.

Sheppard (50) describes a survival mechanism by which the maxillomandibular complex braces itself to provide a stable base for exertion of forces during function.

Brill et al. (12) describing the power comminution of food in the initial stages of mastication indicate that during this stage the mandible takes up a retruded position which places it closer to the centre of the base of skull and in a position of greatest mechanical advantage and security. In this position the mandible is able to exercise greater stresses on the food without any traumatic effects upon the masticatory apparatus itself.

All these above observations can be interrelated and expressed as efforts aimed at best performance with maximum self-preservation. The observations in this investigation in respect to the envelope of movement space i.e. (i) the axial rotation of the envelope of movement space towards the preferred side, (ii) the greater capacity for distal excursions on the preferred side, (iii) which is much more pronounced in the edentulous subjects than in the dentulous, also appear to be complimenting the phenomena observed by these authors. (20, 50, 12)

The observations in the present investigation suggest a hypothesis that: (i) the envelope of total movement space can be divided into four quadrants, i.e. two right and left posterior and two right and left anterior, the dividing boundaries being extensions of X, Y and Z axes into planes passing through

the intercuspal position, (ii) the posterior quadrant on the preferred side (right side in the subjects examined) would offer the mandible maximum stability and security and greater mechanical advantage and that (iii) whenever the mandible is called upon to exercise greater masticatory stresses, it would function in the posterior quadrant on the preferred side, and (iv) this need to recede to the posterior quadrant on the preferred side in the envelope of total movement space would become much greater in the edentulous state and (v) be provided for by the further distal extension of at least the occlusal part of the envelope of total movement space on the preferred side.

The validity of the above hypothesis was verified by examining the Positional Preference of simulated chewing and masticatory cycles in the envelope of total movement space.

Positional Preference of Simulated Chewing Movements in the Dentulous and Edentulous Subjects:

1. In the dentulous subject although during ad lib. performance the closing strokes passed on the preferred side and close to the C.V.A. in the frontal view, in the sagittal view the movements were generally executed anterior to the C.V.A. and the closing strokes passed anterior to the opening strokes. During performance on the designated sides, in the frontal view, the closing strokes showed a tendency to be located on the prescribed side, but in the sagittal view generally passed distally to the opening strokes particularly in the terminal parts.

It was also found that whereas ad lib. exercises displayed a smooth cyclic pattern, a well contained narrow envelope

of movement space used and ease of performance, the simulated chewing exercises on the sides showed irregular patterns, with cycles in different directions, a wide envelope of movement space used and a general awkwardness in performance.

2. In the edentulous subjects there was a strong tendency for the ad lib. simulated chewing cycles to be performed not only on the preferred side but also in the preferred quadrant posterior to the C.V.A. During simulated chewing movements on the sides, similar to the dentulous subject, the closing strokes passed on the designated sides but generally posterior to the C.V.A. and also posterior to the opening strokes.

Collectively these observations suggest that simulated ad lib. exercises requiring no extraordinary efforts were executed by the dentulous subject on the preferred side but not necessarily in the posterior secure quadrant on that side, while the edentulous subjects, handicapped by the displaceability of the dentures not only performed on the preferred side but also in the posterior quadrant on that side, which offered greater security. Similarly simulated chewing performances on the designated sides though not extraordinary for the dentulous subject were not a usual performance so the closing strokes were performed on the designated sides but closer to the posterior quadrant than the opening strokes. In the edentulous subjects the closing strokes passed distally to the opening strokes and also distally to the C.V.A.

Positional Preference of Masticatory Cycles in the Envelope of Total Movement Space in the Dentulous and Edentulous Subjects:

This was determined by calculation of the Positional

Preference Index (P.P.I.) and can be summed up as follows:-

1. Whereas the dentulous subject performed the masticatory movements in a space evenly dispersed on the preferred and non preferred sides, anteriorly as well as posteriorly to the C.V.A., in the total edentulous sample there was a very marked tendency to perform in the preferred quadrant of the total movement space.
2. In both the dentulous and edentulous subjects during the 1st and 3rd Phases of the masticatory sequences there was a greater tendency for the masticatory cycles to be performed in the preferred quadrant of the total movement space. This may possibly be related to firmer consistency of food during the 1st Phase and probably a physiological demand for finer grinding of the bolus in the 3rd. Phase. During the 2nd Phase, whereas in the dentulous subject the movements took place generally anterior to the C.V.A. with a P.P.I. value of -3, in the edentulous subjects the P.P.I. value being +10 these movements generally occurred in the preferred quarters but with a comparatively lower tendency than in other phases. This may possibly be related to such activities as repositioning of the larger-sized food particles on the occlusal surfaces, attempts at dislodgement of the jammed food from the occlusal surfaces and searching for such particles as may have shifted farther away from the occlusal surfaces. All these activities involve lateral, protrusive and open/close movements of greater amplitude which become necessary due possibly to lesser amount of saliva during this phase.
3. The P.P.I. value for individual exercises in the dentulous and edentulous subjects indicated the positional preference for kinematic performance in respect to the

consistencies of food as well as the quantities.

(i) "P.C. ad lib. Exercise":

It represented a small bolus of soft brittle food. The dentulous subject crushed the bolus completely in the first closing stroke which was performed in the preferred quadrant of the total movement space. The subsequent masticatory cycles were performed more freely, hence the higher negative P.P.I. value of -10.

In the edentulous subjects most of the masticatory cycles were performed in the preferred quarter with a P.P.I. value of +12.

(ii) "P.C.F.M. ad lib. Exercise":

The exercise differed from the P.C. ad lib. exercise only in the largeness of the size of bolus. This affected the P.P.I. values in both the dentulous as well as edentulous subjects. The P.P.I. value of +7 in the dentulous subject showed a definite preference for performance in the preferred quarters. Similarly the higher positive P.P.I. value of +15 in the edentulous subjects indicated a very strong preference for the preferred quadrant.

During the 1st Phase of this exercise the average P.P.I. value of +17 was calculated for the total edentulous sample which shows an even stronger tendency for performance in the preferred quadrant.

(iii) M.C. ad lib. Exercise:

The exercise represented a small bolus of firm and tough

food that maintained its form throughout the masticatory sequence. The dentulous subject showed a P.P.I. value of +6 while the edentulous subjects showed a P.P.I. value of +14 indicating that in both types of subjects the masticatory cycles were performed mostly in the preferred quarters. A P.P.I. value of +17 in the 3rd Phase of the edentulous performance indicating an increased tendency to perform in the distal quadrant on the preferred side than in other phases, is suggestive of the consistent effort required during meat chewing.

(iv) . S.D.C. ad lib. Exercise:

The size of the bolus of food was the smallest of all the exercises, but represented a hard brittle consistency. The dentulous subject showed a P.P.I. value of -3 and the edentulous subjects +10, indicating that whereas in the dentulous subject the movements were performed generally anteriorly, in the edentulous subjects the performance took place in the preferred quarters. A P.P.I. value of +15 during the 1st Phase, a higher positive figure than in other phases, indicated the greater effort required during this phase.

All these observations indicate the validity of the hypothesis that whenever the mandible is called upon to exercise a greater masticatory effort it performs on the preferred side and in comparatively distal relationship and that this need is more pronounced in the edentulous subjects than in the dentulous.

Hildebrand ⁽²⁰⁾ indicated that "as a rule, the nature of the food does not influence the appearance of the masticatory curve (cycle) in any respect. Ahlgren ⁽¹⁾ has presented a

classification of the form of masticatory cycles based on a two-dimensional assessment of the masticatory cycles. He also has not been able to attribute any functional significance to the particular patterns observed.

On the basis of the Positional Preference Index (a three-dimensional assessment), the total masticatory kinematic performance of a subject or a masticatory sequence or part of a sequence or a masticatory cycle or even part of a cycle can be classified as Conservative or Non-Conservative indicating the functional quality of the particular performance.

Conservative Masticatory Kinematic Performance:

Conservative Masticatory Kinematic Performance would have a positive P.P.I. value and can be defined as a performance in which:

- a. A majority of masticatory cycles initiated from intercuspal position or closed mouth position located on the preferred side and posterior to the C.V.A.
- b. The opening strokes commence on the preferred side and posterior to the C.V.A.
- c. The opening strokes reach maximally open position on the preferred side and posterior to the C.V.A.
- d. The maximal openings may show a "Point" form or a "Loop" form.
- e. The closing strokes pass on the preferred side and posterior to the C.V.A.
- f. The closing strokes pass closer to the C.V.A. than the opening strokes and posterior to them.
- g. The closing strokes terminate in intercuspal position or closed mouth positions located posterior to the C.V.A.

The higher the positive value of the P.P.I. the more conservative the performance.

Non-Conservative Masticatory Kinematic Performance:

Non-Conservative Performance can be defined as a performance in which most of the movement space used is located on the non-preferred side and/or anterior to the C.V.A. thereby at least theoretically exposing the movable component of the masticatory apparatus to possible traumatic conditions. A non-conservative performance would have a negative P.P.I. value. Whereas a very high negative P.P.I. value would indicate a possible error in the determination of the preference for the side for mastication, a low negative P.P.I. value only indicates that although most of the movement space used during a performance was located on the non-preferred side, some of the movement also occurred on the preferred side. This is very clearly illustrated during P.C. ad lib. exercise performed by the dentulous subject. (Figs. No. 50, 51) Only the 1st Phase of the exercise was performed on the preferred side, both the 2nd and 3rd Phases were performed on the left side of the C.V.A. although throughout the exercise the subject chewed the food between the teeth on the right or the preferred side.

The P.P.I. value of zero as seen in the total dentulous performance indicated a "Neutral" performance, meaning that the space used was evenly dispersed on the preferred and non-preferred sides and anterior and posterior to the C.V.A. The dentulous subject did not show any definite positional preference for the performance of the masticatory cycles. This can be interpreted as a higher degree of proficiency of the dentulous masticatory apparatus. The subject performed in the posterior quadrant on the preferred side only when

he was required to exert some real effort, as during P.C.F.M. ad lib. exercise or M.C. ad lib. exercise.

The total edentulous sample masticatory kinematic performance showed a P.P.I. value of +12 indicating a definite selective tendency towards positional preference for the performance of the masticatory cycles. This can be attributed to the handicapped nature of the edentulous masticatory apparatus. Unlike the dentulous subject carrying out similar exercises, the edentulous masticatory apparatus performed most of the masticatory movements in the posterior quadrant on the preferred side. In other words the edentulous masticatory apparatus needed greater security for the performance of similar exercises than the dentulous apparatus.

Again, the dentulous subject during the performance of P.C. ad lib. exercise showed a negative P.P.I. value of -10, and for the P.C.F.M. ad lib. exercise a positive value of +7. In the edentulous subjects the P.P.I. values for the above two exercises were +12 and +15 respectively. In other words both the dentulous and the edentulous subjects performed with greater caution when the size of bolus was increased. The significance of the size of bolus is also evident from a comparison of the P.P.I. value of M.C. ad lib. and S.D.C. ad lib. exercises with that of the P.C.F.M. ad lib. exercise.

The P.P.I. values for the 1st and 3rd Phases in both the dentulous and edentulous subjects indicated a comparatively conservative performance than in the 2nd Phase.

All the above observations in the dentulous and edentulous subjects and in respect to the different exercises and the different phases during the performance indicate that:

1. The Masticatory Kinematic Performance in the edentulous state is different from that in the dentulous state, the former being more conservative than the latter.
2. The performance varies as the consistency of food is varied. It is more conservative for tough and hard foods than for soft and brittle foods.
3. The performance varies as the size of bolus varies, the larger bolus requiring a more conservative performance than the smaller.
4. The performances changes during the different phases of the masticatory sequence, being more conservative in the 1st and 3rd Phases than in the 2nd Phase.

II. ROLE OF CUSPAL GUIDANCE:

The occlusal parts of the simulated and masticatory movements were compared to the frontal elevation of the posterior superior boundary and the sagittal elevation of the median superior border of the envelope of total movement space either indirectly through tangent angles as for the simulated chewing movements or directly with the help of transparencies as for the masticatory movements. Thus assessment of the movements occurring between these border paths was only arbitrary. These border paths, being the highest in the occlusal boundary of the total envelope of movement space, (which is not a flat "surface" (38, 39) it is likely that many tooth contacts that occurred below the level of these paths were omitted. In other words actual incidence of cuspal guidance could possibly be higher than that determined by these methods.

The incidence of cuspal guidance, the location of cuspal guidance and also the type of tooth contact during cuspal guidance are all issues surrounded by considerable controversy. Jankelson et al. (25) did not find any tooth contact at all during mastication. Graf et al. (71),

Beyron ⁽⁷²⁾ and Woelfel et al. ⁽⁶⁴⁾ found numerous tooth contacts during mastication. Ahlgren ^(1, 2) found a variable incidence, there were subjects who did not show any tooth contact while others displayed an incidence as high as 84%. Again Graf et al. ⁽⁷¹⁾, Ahlgren ^(1, 2), Beyron ⁽⁷²⁾ and Gibbs et al. ⁽¹⁶⁾ indicate occurrence of tooth contact at the intercuspal position only. Hildebrand ⁽²⁰⁾, Graf et al. ⁽⁷¹⁾ and Beyron ⁽⁷²⁾ describe varying distances and durations of intercuspal glide.

Examination of the simulated chewing movements revealed that during these exercises, both in the dentulous as well as the edentulous subjects, the ultimate tooth contact between the opposing natural or artificial dentitions occurred in the maximally intercuspated maxillomandibular relationship. The jaw point could move in or out of the intercuspal position either directly without any other tooth contact except that in the intercuspal position or follow a lateral medial or/and protrusive or retrusive course during opening and closing movements respectively and be guided in or out of the intercuspal position by extended eccentric tooth contacts resulting in mutual gliding of cuspal inclines of the opposing occlusal surfaces.

During assessment of the masticatory movements, it was found that in addition to the intercuspal position, ultimate tooth contact between the opposing dentitions could also occur in eccentric maxillomandibular relationships. The opposing teeth came into contact in eccentric relations and without reaching the intercuspal position the jaws separated, thus initiating the opening strokes.

In this investigation all eccentric tooth contacts whether leading the mandible to or from intercuspal position or resulting in initiation of the opening strokes were considered conducive to cuspal guidance.

Due to the incomplete nature of the assessment of the incidence of cuspal guidance in this present investigation, observations are presented without any comparative comments.

Incidence of Cuspal Guidance:

Not only was the incidence of cuspal guidance higher in the edentulous sample than in the dentulous subject, it was also more involved in the masticatory cycles. In the majority of cycles showing cuspal guidance in the edentulous performance, the influence could be seen in both the opening and closing strokes of the same cycle and in 15% of the cycles in both the frontal and sagittal views of the opening and closing strokes of the same cycle.

The lower incidence of cuspal guidance in the edentulous subject 'D' can be attributed to poorer stress-bearing qualities of the soft tissues covering the denture-bearing areas.

The incidence of cuspal guidance varied in the three phases of the masticatory sequences, and the patterns differed in the dentulous and edentulous subjects. In the dentulous subject the incidence was highest in the 1st Phase, lower in the 3rd Phase and lowest in the 2nd Phase. In the edentulous subjects the incidence of cuspal guidance in the three phases progressively increased as the mastication progressed. During the 2nd Phase a greater number of masticatory cycles showed cuspal guidance influencing both the opening and closing strokes.

Location of Cuspal Guidance:

According to the location of cuspal guidance in the simulated chewing and masticatory movements four different

types of movement cycles were recognised:

1. "Direct Chewing Cycles": The cycles were executed without any cuspal guidance at all. These were common in the dentulous subject.
2. "Double Chewing Cycles": The cycles initiated with cuspal guidance and also terminated with cuspal guidance. These cycles were more common in the edentulous subjects and during the 2nd Phase, of the masticatory sequences.
3. "Conventional Chewing Cycles": The cycles initiated without any cuspal guidance but the closing stroke terminated with cuspal guidance. These were more common in the 2nd Phase of the dentulous performance.
4. "Reverse Chewing Cycles": Cuspal guidance appeared only at the initiation of the opening stroke, the cycle terminated without cuspal guidance. Such cycles were more common in the 3rd Phase of the dentulous performance.

Direction of Motion During Cuspal Guidance:

Cuspal guidance could be seen in (i) only the frontal view of the movement cycle, or (ii) only in the sagittal view of the cycle and also (iii) in both the views of the same cycle.

(i) Cuspal Guidance Only in the Frontal View

This indicated a greater lateral component in the particular part of the movement cycle and can be referred to as "Lateral Cuspal Guidance". When occurring in the opening stroke it involved a movement in a medio-lateral direction. When it occurred in the closing stroke the movement took place in a latero-medial direction.

(ii) Cuspal Guidance Only in the Sagittal View:

This indicated a dominant protrusive or retrusive component in the jaw point movement in the particular part of the cycle, and accordingly can be referred to as "Protrusive" or "Retrusive" cuspal guidance.

Protrusive cuspal guidance in the dentulous subject was essentially a feature of the opening stroke, but in the edentulous subjects it occurred in both opening as well as closing strokes. During the closing stroke it guided the jaw point to the intercuspal position from a postero-anterior direction. Retrusive cuspal guidance in both types of subjects occurred only in the closing strokes.

(iii) Cuspal Guidance in the Frontal and Sagittal Views of the same cycle indicated a lateral and protrusive or retrusive movement of the jaw point.

Types of Cuspal Guidance:

Two basic types of cuspal guidance were recognised:

1. Point Reflective Cuspal Guidance:

The closing stroke terminated in an eccentric inter-occlusal contact and without any intercuspal sliding the next opening stroke initiated from the same eccentric point of contact. Although the definition of "Point Reflective Cuspal Guidance" does not conform with the conventional concept of the term "Cuspal Guidance" in that it does not involve any intercuspal sliding, it was considered as such on the basis that the eccentric intercuspal contact guided the jaw into the next opening stroke. Point reflective cuspal guidance essentially occurred between a closing stroke and the next opening stroke. The closing stroke appeared to be reflected back

as the next opening stroke forming an acute angle at the point of intercuspal contact.

2. Sliding Deflective Cuspal Guidance:

Tooth contact occurred in an eccentric inter-occlusal relationship during an opening or a closing stroke. The cusps glided against one another along a border path and resulted in a further opening or closing of the jaw. During sliding deflective cuspal guidance the intercuspal contact deflected the path of opening or closing strokes generally through an obtuse angle. Essentially the sliding deflective cuspal guidance formed a part of an opening or closing stroke, but at times was shared by two consecutive cycles, forming a part of one closing stroke and also continuing into the next opening stroke.

Both types of cuspal guidance could be seen in the frontal and sagittal views of the masticatory cycles.

Functions of the Two Types of Cuspal Guidance:

1. Functions of Point Reflective Cuspal Guidance:

Considering the manner of inter-occlusal contact, it appeared that point reflective cuspal guidance would act very similar to a hammer or a meat tenderising mallet that struck a blow and rebounded from the very spot. Thus it would impart to the masticatory cycle qualities to (i) crush brittle and hard foods, (ii) soften or tenderise firm and tough foods and (iii) possibly in the presence of enough food exercise a pumping action on the occlusal surfaces, clearing them of jammed food particles from previous strokes. Thus a closing stroke in such cycles would be a crushing stroke. It is likely that these would not be the only crushing strokes

in a sequence, the closing strokes terminating directly in the intercuspal position or positions posterior to it and, having a lesser degree of lateral component of motion, show greater potentialities to perform such functions. The closing strokes showing point reflective cuspal guidance could be considered a variation of the crushing strokes.

2. Functions of Sliding Deflective Cuspal Guidance:

Sliding deflective cuspal guidance appeared to exercise a shearing, shredding or grinding action upon the food and could be expected to give the masticatory cycle qualities for (i) finer pulverisation of brittle foods, (ii) tearing and teasing of fibrous foods and (iii) dislodgement of jammed food particles from the occlusal surfaces. Whereas reflective cuspal guidance acted through the stronger vertical component of motion, the deflective cuspal guidance acted through the stronger horizontal component in the movements.

Some of these functions could be detected during the performance of different exercises, e.g.:

(i) The greater incidence of sliding cuspal guidance in the 1st Phase and point cuspal guidance in the later phases of the "P.C. ad lib." exercise in the edentulous subjects could be attributed to the sticky nature of the bolus in the earlier parts of the sequences, possibly due to smaller amount of saliva in the mouth at that time. This jammed the occlusal surfaces and required a sliding contact between the teeth for occlusal clearance. As the mastication progressed, the bolus became more fluid in nature, facilitating its manipulation and transport by the tongue and cheeks. Uncrushed food particles were more readily available on the occlusal

surfaces for further crushing and could be managed with comparatively vertical strokes with point or no cuspal guidance at all.

(ii) The same is borne out in the "P.C.F.M. ad lib" exercise. An abundant amount of food was readily available on the occlusal surfaces, so the masticatory cycles were generally of a "direct" pattern with less lateral component, eccentric inter-occlusal contacts or cuspal guidance.

(iii) During "M.C. ad lib." exercise the bolus presented a tough and fibrous consistency. Accordingly in the 1st Phase 40% of the strokes initiated and terminated directly without any cuspal guidance, representing vertical strokes, 30% of the strokes showed point reflective cuspal guidance, representing eccentric crushing strokes and only about 30% of the strokes showed sliding cuspal guidance. Thus the meat bolus in the 1st Phase was mostly subjected to piercing and penetrating action of the cusps. The greater incidence of sliding cuspal guidance in the later phases produced a rolling of the bolus in the mouth, teasing the fibres apart and impregnating them with saliva.

The exact nature of the differences between the dentulous and edentulous states can be assessed only after examination of the movements of the food bolus in the mouth and the changes it undergoes during the different phases of the masticatory sequences.

The observations in respect to cuspal guidance conform with the observations by Shearer et al. (75, 78) and Sheppard and Sheppard (74), particularly in regard to the type and manner

of cuspal guidance. In edentulous subjects Sheppard and Sheppard ⁽⁷⁴⁾ appear to have recorded a much higher incidence of direct closures i.e. strokes without any cuspal guidance, correspondingly the number of cycles showing cuspal guidance has been indicated as very low (about 30%). On the other hand, the present investigation, owing to the limitations of the procedure, is considered incomplete in regard to assessment of the incidence of cuspal guidance, the number of edentulous masticatory cycles showing cuspal guidance influence being as high as 66%, only 34% cycles followed direct paths.

This difference in the assessment in the two investigations can be attributed to:

1. Sheppard and Sheppard ⁽⁷⁴⁾ have examined only the closing strokes and only in the frontal view. The present investigation shows cuspal guidance involvement of both the opening and closing strokes and in both frontal and sagittal views.
2. In the investigation referred to ⁽⁷⁴⁾ nearly three quarters of the subjects used dentures with cuspid-protected occlusion that either did not allow lateral movements at all or limited lateral excursions considerably. In the present investigation the usual occlusal adjustments were made in the dentures to facilitate lateral movements. As indicated by Ramfjord ⁽⁷⁹⁾, the mandible has a tendency to use freedom in lateral movements when the latter are possible. Butler and Zander ⁽⁷⁶⁾ observed that whenever cuspid-protected occlusion was changed to a multicontact type there was a significant increase in the number of eccentric contacts.
3. Again Sheppard and Sheppard ⁽⁷⁴⁾ used only one food i.e. oatmeal biscuits for their experiment. In the present

investigation three different foods were used and each exercise showed different incidence of cuspal guidance. The variations of cuspal guidance with different foods is also confirmed by Anderson and Picton ⁽⁷⁷⁾. According to their observations very few occlusal contacts occurred during mastication of biscuits.

III. ENVELOPE OF MOVEMENT SPACE USED DURING MASTICATION

As indicated by Schweitzer ⁽⁴³⁾, Sheppard ⁽⁵²⁾, Atkinson and Shepherd ⁽⁷⁾, Rudd et al. ⁽⁴²⁾ and Woelfel et al. ⁽⁶⁴⁾ it was found that the envelope of movement space used during mastication was much smaller than the envelope of total movement space, and was even smaller for edentulous subjects. Atkinson and Shepherd ⁽⁷⁾ consider this smallness of the size of functional envelope in the edentulous subjects similar to the limitation of movements of other parts of the body due to senile atrophy.

The vertical dimension of the functional envelope in the edentulous subjects was nearly half that in the dentulous subject. Murphy ⁽³³⁾ in his observations on Australian aboriginals indicates that mandibular descent "in each stroke is just sufficient to grasp the food bolus. There is no free ascent" prior to contact with food. In this present investigation there was considerable evidence to the contrary. In the dentulous subject mouth opening during Meat Chewing exercise varied from 2.2 cm. to 2.7 cm. for a 1.0 cm. cube bolus size. Similarly in the edentulous subjects mouth opening for the same exercise generally exceeded the size of the bolus.

In both the dentulous as well as edentulous subjects there did not appear to be any relationship among (i) the size of the food bolus, (ii) the phase of masticatory sequence, and (iii) the extent of mouth opening. On the other hand there was some evidence relating the

consistency of food to the maximal opening during a masticatory cycle. In both dentulous as well as edentulous subjects maximal mouth opening during mastication occurred in "M.C. ad lib." and "S.D.C. ad lib." exercises. In the former the opening increased as the mastication progressed, while in the latter the opening decreased with the progress of mastication. This relationship between the mouth opening and the consistency of food bolus is suggestive of the ballistic nature of the closing stroke. The increase or decrease in the mouth opening during a performance seems to regulate the momentum gained by the mandible during the closure in respect to the particular requirements of the food bolus.

In the dentulous subject during "P.C.F.M." ad lib. and "M.C. ad lib." exercises most of the movement space used was located in the posterior quadrant on the preferred side. During "P.C. ad lib." and "S.D.C. ad lib." exercises, although the first cycles were executed posterior to the C.V.A., most of the space used was located on the non-preferred side and anterior to C.V.A. As only a single dentulous subject was examined, there was insufficient evidence to indicate conclusively any preference for a particular quarter of the envelope of total movement space during masticatory kinematic performance.

In the edentulous subjects most of the space used during mastication was generally located on the preferred side and posterior to the C.V.A. The edentulous subject 'C' tended to perform anteriorly to the C.V.A. This could possibly be related to the fact that the subject had not used the lower denture for some time and performed mastication with the mandible in a habitually protruded position against the upper denture. As suggested by Sheppard and Sheppard ⁽⁵³⁾, this phenomenon could be due to a persisting "muscle memory or neuromuscular habit" executing these customary movements. Lammie et al. ⁽⁸¹⁾ in their work "Observations on a complete denture patient, III" also consider a residual memory of a previously existing intercuspal position, natural or artificial, responsible for such aberrations.

As indicated by Schweitzer ⁽⁴³⁾, the envelope of functional movement space in the dentulous subject was narrow, with a smooth and well contained outline form. Gibbs et al. ⁽¹⁶⁾ relate this smoothness and regularity of the envelope to normality of occlusion. In the edentulous subjects the different masticatory cycles were executed in different directions, thus both the frontal and sagittal views of the envelope showed irregular outline. There was a tendency to smoother and more contained performance in the later phases of the masticatory sequences. In both dentulous and edentulous subjects the smoothest outline of envelope of functional movement space was seen during "M.C. ad lib." exercise. This appears to be related to the property of a meat bolus to maintain a form throughout the sequence. The bolus did not break down or spread out in the mouth, so the number of food-finding excursions was comparatively lower, resulting in a smoother envelope.

The comparatively greater lateral excursions and deviations in the edentulous subjects may also be attributed to the impaired proprioception due to loss of teeth and also coverage of the oral surfaces by the dentures.

Location of the Intercuspal Position in Relation to the Envelope of Movement Space Used During ad lib. Mastication:

In the dentulous subject only the first cycle in each sequence initiated from the intercuspal position, all other cycles initiated from and terminated in open mouth positions. These terminal points of the masticatory cycles were located at an average vertical distance of 0.72 mm. from the intercuspal position. It was also observed that at a vertical distance of 0.5 mm. from the intercuspal position the terminal points of the masticatory cycles were invariably located directly below the intercuspal position on the C.V.A. in both frontal as well as sagittal views. As the vertical distance increased the terminal points of the masticatory cycles could be located on the right

and left sides of the C.V.A. At a distance of 1.8 mm. from the intercuspal position the cycles could also terminate posterior to the C.V.A. This indicates that in the dentulous subject the points of initiation and termination of the masticatory cycles were generally confined to the intercuspal position, separated from it only by the thickness of food between the teeth. Similar observations have been reported by Schweitzer (43), Nemoto et al. (35), Ahlgren (1, 2) and others (5, 33, 52) in dentulous subjects.

In the edentulous subjects on the other hand although the occlusal ends of the masticatory cycles fell short of the intercuspal position by an average distance of 1.03 mm., more than one third of the cycles reached the inter-occlusal level and terminated in the intercuspal position and also in positions located anteriorly, posteriorly or on the right and left sides of the intercuspal position. This conforms with the observations by Silverman (56) and Campbell (13). Campbell indicates that when capsular ligaments are torn or weakened there is bound to be resiliency in the joint, and the condyles can move into more distal positions. He contends that this can happen in edentulous subjects.

SECTION IX

CONCLUSIONS

CONCLUSIONS

The function of mastication is influenced by factors ranging from a wide disposition of neurological controls to an equally wide range of individual habits, food preferences and qualitative and quantitative properties of the food bolus. The resultant variations are so numerous that a movement cycle had to be subjected to as many as 150 observations. As such a small sample of subjects was examined in this investigation no generally applicable firm conclusions can be drawn.

The following are presented as findings on the subjects examined:

ENVELOPE OF TOTAL MOVEMENT SPACE:

In both Dentulous and Edentulous Subjects the envelopes of total movement space agree in some aspects and differ in others.

1. Points of Resemblance:

- (a) The envelopes are generally rhomboidal in cross-section and inverted pyramidal in form. The rhomboidal base of the pyramid represents the occlusal or the superior boundary of the envelope and the pointed apex the maximally open position.
- (b) The jaw can move freely in the total movement space but for the performance of masticatory movements there appears to be a preference for some parts of the envelope. This preference may be due to a greater mechanical advantage and a greater security offered to the mandible by the relationship of these parts to the base of the skull.
- (c) The envelope of movement space appears to be rotated around a vertical axis towards the preferred side. This is due
 - (i) to the retruded lateral excursion paths on the preferred side being located farther posteriorly than on the other

side, and (ii) to the retruded lateral excursion paths on the non-preferred side extending farther out laterally and anteriorly. Consequently the lateral acute angle on the preferred side of the rhomboid occlusal boundary of the total envelope is wider than on the other side. This indicates that at the interocclusal level the capacity for distal motion is greater on the preferred side and the capacity for lateral motion greater on the non-preferred side.

2. Points of Difference:

- (a) The envelope of total movement space in the Edentulous Subjects was smaller in all dimensions in comparison to that of the Dentulous Subject.
- (b) In the Dentulous Subject the intercuspal position was the maximally retruded border position in the occlusal boundary of the envelope of total movement space. The mandible could be forced to a further distal position but lost the ability to perform sliding contact lateral excursions, only open/close movements being possible from this forced position.
- (c) In the Edentulous Subjects the apex of the gothic arch tracing was not a border position, the mandible could be shifted further distally and still perform sliding contact lateral excursions unassisted. Such excursions passed even further distally to the maximally retruded position at the interocclusal level in their mid-course but at levels some distance below the interocclusal level. This gave the posterior superior boundary of the envelope of total movement space a cleft appearance in the horizontal view. Thus the capacity for distal excursion was greater in the Edentulous masticatory apparatus and was greater on the preferred side. This appeared

to be due to laxness of the temporomandibular ligaments in the Edentulous State.

- (d) Whereas the maximally retruded open/close movement path in the Dentulous Subject was broken in the middle by an obtuse angle, indicating the point of compulsory protrusive translation of the condyles; in the Edentulous Subjects the path was more or less a continuous arc suggesting a stretch of the weakened ligaments under stress..

SIMULATED CHEWING MOVEMENTS:

1. In both the Dentulous and Edentulous Subjects the simulated ad lib. performances were executed on the preferred side.
2. The ad lib. simulated chewing movements were performed with greater ease and control than performances under instruction and on designated sides. The Dentulous Subject could perform these movements with better control than the Edentulous Subjects.
3. Whereas in the Dentulous Subject the movements initiated from and terminated in intercuspal position, in the Edentulous Subjects the movements initiated from and terminated in a wider area at the inter-occlusal level.
4. In the particular Dentulous Subject the consistent protrusive component during the entire opening stroke and earlier part of the closing stroke indicated protrusive translation of the mandible beginning with the initiation of the opening stroke, continuing throughout the opening stroke and the earlier parts of the closing stroke, changing into retrusive translation only in the terminal parts of the closing stroke.
5. In the Edentulous Subjects there was a consistent retrusive component during the opening strokes and a protrusive component during the closing strokes. This indicates a

lesser protrusive translation of the entire mandible in the Edentulous Subjects but does not preclude the possibility of a protrusive translation of the condyles occurring due to rotation of the mandible around a transverse axis located somewhere below the level of the condyles.

6. In the Dentulous Subject, simulated chewing movements in addition to the protrusive component also displayed varying degrees of lateral components. This indicated that translatory movements of the "Working Side" condyle are possible from the initiation to the termination of the cycles. The rotation of the mandible towards the "Working Side" appears to be due to the "Balancing Side" condyle moving faster than the "Working Side" condyle assisted by Bennett Movement.
7. Simulated chewing movements in the Edentulous Subjects also displayed lateral components. A considerable number of closing strokes were located distally to the C.V.A. and also terminated distal to the intercuspal position. Under these circumstances lateral deviations during these movements would result in a rotation of the mandible around a vertical axis located somewhere on the medial aspect of the "Working Side" condyle. The "Balancing Side" condyle would move downward and forward and the "Working Side" condyle distally and possibly laterally.
8. The terms "Working Side" and "Balancing Side" have only a didactic significance. The subjects could pretend chewing on the right side with the right condyle moving downward and forward in the "Balancing Side" position and the left condyle taking up the theoretical "Working Side" position.
9. The amplitude of simulated movements in the Dentulous Subject was much greater than in the Edentulous Subjects.

MASTICATORY MOVEMENTS:

Mastication although a very variable function, in the subjects examined did show some constancies in respect to:

- I. Positional relationships of the opening and closing strokes.
- II. The role of cuspal guidance.
- III. The envelope of total movement space used.

I. POSITIONAL RELATIONSHIPS OF THE OPENING AND CLOSING STROKES:

1. Whereas in the Dentulous Subject the points of initiation and termination of the masticatory cycle were more closely related to the intercuspal position, though separated from it by the intervening food, in the Edentulous Subjects these points appeared dispersed all around, at the intercuspal position and posterior to it, at the inter-occlusal level and also at open-mouth positions. The maximally retruded functional position in the Edentulous Subjects appeared to be located further distally to the apex of the gothic arch tracing.
2. In the Edentulous Subjects there was a definite preference for the masticatory cycles to be performed on the preferred side and closer to the posterior border of the total movement space. Similar tendencies existed in the Dentulous Subject but to a limited extent. This positional preference appeared to be related to the need for the development of maximal mechanical advantage during performance and also preservation of the masticatory apparatus.
3. The Masticatory Kinematic Performance of a subject can be assessed and classified as "Conservative" or "Non-Conservative":

The Conservative Masticatory Kinematic Performance would have a positive Positional Preference Index

value and can be defined as a performance in which:

- (a) A majority of the masticatory cycles initiate from the intercuspal position or closed-mouth positions located on the preferred side and posterior to the C.V.A.
- (b) The opening strokes generally commence on the preferred side and posterior to the C.V.A.
- (c) The opening strokes generally reach maximally open positions on the preferred side and posterior to the C.V.A.
- (d) The maximal opening may show either a "Point" form or a "Loop" form.
- (e) A majority of the closing strokes pass on the preferred side and posterior to the C.V.A.
- (f) Most of the closing strokes pass closer to the C.V.A. than the opening strokes and also posterior to them.
- (g) The closing strokes terminate in intercuspal position or closed-mouth positions located posterior to the C.V.A.

The greater the incidence of these individual preferences the higher the positive value of the Positional Preference Index and more "Conservative" the performance.

The "Non-Conservative" performance can be defined as a performance in which the above features are generally performed on the non-preferred side and/or anterior to the C.V.A. The higher the negative value of the Positional Preference Index the more "Non-Conservative" the performance.

A "Conservative" performance would indicate the subject's lesser confidence in his Masticatory Kinematic Performance, and a "Non-Conservative" performance his greater confidence in his masticatory apparatus.

4. The Masticatory Kinematic Performance in the

Edentulous Subjects was more "Conservative" than in the Dentulous Subject.

5. In both Dentulous and Edentulous Subjects during mastication of hard, tough, and firm foods the Masticatory Kinematic Performance was more "Conservative" than with soft and brittle foods.
6. In both types of subjects during mastication of sticky foods the performance is less "Conservative" or may even require to be "Non-Conservative". Such foods required a stronger lateral component in the masticatory cycles to clear the food jamming on the occlusal surfaces. The Edentulous Subjects generally tend to avoid such foods.
7. The Masticatory Kinematic Performance was more "Conservative" in the 1st and 3rd Phases of the masticatory sequences than in the 2nd Phase.

II. THE ROLE OF CUSPAL GUIDANCE:

1. During simulated or masticatory movements in the Dentulous Subjects tooth contacts occurred in the intercuspal position and also in eccentric inter-occlusal relations. Tooth contacts in the eccentric inter-occlusal relations have been referred to as Cuspal Guidance.
2. The incidence of cuspal guidance was not only higher in the Edentulous Subjects than in the Dentulous, it was also more involved in the masticatory cycle. It occurred at both ends of a cycle and also appeared in both the frontal and sagittal views.
3. On the basis of location of cuspal guidance in the chewing cycle, a classification of the chewing cycles is suggested:

(a) Conventional Cycles:

Cuspal guidance occurring only in the closing strokes. Such cycles were common in the Dentulous performance and in the 2nd Phase.

(b) Reverse Chewing Cycles:

Cuspal guidance occurring only at the commencement of the opening strokes. Such cycles were common in the 3rd Phase of the Dentulous performance.

(c) Double Chewing Cycles:

Cuspal guidance occurring at both ends of the cycles. These were common in the 2nd Phase of the Edentulous performance.

(d) Direct Chewing Cycles:

The cycles starting and terminating at the intercuspal position directly without any cuspal guidance. These were common in the Dentulous Subject but also occurred in the Edentulous performance.

4. During cuspal guidance movement occurred:

- (i) From medial to lateral direction during the opening strokes (seen in the frontal view).
- (ii) From lateral to medial direction during the closing strokes (seen in the frontal view).
- (iii) In protrusive or retrusive directions (seen in the sagittal view).

In the Dentulous Subject protrusive movement during cuspal guidance occurred only in the opening strokes. In the Edentulous Subjects protrusive movement during cuspal guidance occurred in opening as well as closing strokes. Retrusive movements were

associated with only the closing strokes and occurred in the Dentulous as well as Edentulous Subjects.

- (iv) Cuspal guidance in both the frontal and sagittal views of the same cycle indicated a simultaneous lateral and protrusive or retrusive excursion.

5. Types of Cuspal Guidance in Respect to the Manner of Intercuspal Contact:

Two basic types of cuspal guidance were observed:

(i) Point Reflective Cuspal Guidance:

It occurred as an eccentric inter-occlusal contact between a closing stroke and the next opening stroke. The occlusal contact did not involve any intercuspal sliding.

(ii) Sliding Deflective Cuspal Guidance:

Tooth contact occurred in an eccentric inter-occlusal relation during an opening or a closing stroke and deflected the path of the stroke.

6. On the basis of the incidence and the types of cuspal guidance the masticatory cycles can be attributed functional qualities:

- (i) Direct cycles can be classed as crushing cycles.
 - (ii) Cycles with Point Reflective Cuspal Guidance in the closing strokes can be classed as eccentric crushing cycles.
 - (iii) Cycles with Sliding Deflective Cuspal Guidance can be classed as grinding masticatory cycles.
- These functions could be detected in the different exercises.

III. ENVELOPE OF MOVEMENT SPACE USED DURING MASTICATION:

- 1. In the Edentulous Subjects the envelope of movement

space used during mastication was much smaller than in the Dentulous Subject. The vertical length of the envelope in the Edentulous Subjects was about one half that in the Dentulous.

2. In both the Dentulous and Edentulous Subjects no relationship could be found between (i) the size of food bolus, (ii) the phase of masticatory sequence and (iii) the extent of mouth opening during mastication.
3. There appeared to be a relationship between the consistency of food bolus and the extent of mouth opening. The harder and firmer foods required a greater amplitude of closing stroke, suggesting a ballistic nature of the stroke, the mandible gathering moment during the closing path.
4. Most of the space used during mastication was located on the preferred side and distal to the C.V.A., particularly in the Edentulous Subjects.
5. The envelope of functional movement space in the Edentulous Subjects had a more irregular outline form than in the Dentulous Subject. This may be due to impaired proprioception through loss of teeth and coverage of the oral surfaces by the Dentures.
6. The smoothness of the outline form of the functional envelope appeared related to consistency and properties of the food bolus:
 - (i) A meat bolus maintained its form and produced the smoothest outline of the functional envelope.
 - (ii) A large-sized bolus reduced the magnitude of lateral deviations and the number of food finding excursions, resulting in smoother outline form of the envelope.

(iii) Sticky foods and a smaller size of the bolus resulted in jamming of the occlusal surfaces and presented irregular envelope outline form.

7. It is suggested that the resiliency of the temporomandibular joint ligaments in the Edentulous Subjects results in the occlusal end of the envelope of functional movement space being a surface at the inter-occlusal level. The surface extending all around the intercuspal position.
 8. The investigation presents ample evidence of the versatility of Photo-electric system of Mandibulography. In addition to Kinematic studies it also makes possible simultaneous Electromyographic assessment of the muscles responsible for the motion (Appendix IV).
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BIBLIOGRAPHY

1. Ahlgren, J. -- Mechanism of mastication. Acta. Odont. Scand.; Vol. 24, Suppl. 44, 1966.
2. Ahlgren, J. -- Kinesiology of the mandible. Acta. Odont. Scand.; Vol. 25, No. 6, Dec. 1967.
3. Ai, M., Ishiwara, T. -- A study of masticatory movements at the incision inferius. Bul. Tokyo Med. Dent. Uni. 15: 359-369, 1968.
4. Atkinson, H.F. -- The masticatory movements of patients after major oral surgery. Jn. Pros. Dent. Vol. 10, No. 1: 86-91, Jan. 1969.
5. Atkinson, H.F., Shepherd, R.W. -- A preliminary report of investigation into mandibular movements. Aust. Dent. Jn. Vol. 59, No. 5: 267-270, Oct. 1955.
6. Atwood, D.A. -- A critique of research of the posterior limit of the mandibular positions. Jn. Pros. Dent. Vol. 20, No. 1:21-36, July, 1968.
7. Atkinson, H.F., Shepherd, R.W. -- Masticatory movements and tooth form. Aust. Dent. Jn. : 49-53, Feb. 1967.
8. Ballard, C.F. -- Mandibular posture. Dent. Practit. Vol. 17, No. 11: 372-383, July 1967.
9. Bennett, N.G. -- A contribution to the study of the movements of the mandible. (1908) Reprint. Jn. Pros. Dent., Vol. 8, No. 1:41-54, Jan. 1958.
10. Berry, D.C. -- The constancy of the rest position of mandible. Dent. Practit., Vol. 10, No. 6: 129-132, Feb. 1960.
11. Boucher, L.J. -- Limiting factors in posterior movements of mandibular condyles. Jn. Pros. Dent., Vol. 11, No. 1: 23-25, 1961.
12. Brill, N., Lammie, G.A., Osborne, J., and Perry, H.T. -- Mandibular positions and mandibular movements. A review. Brit. Dent. Jn., Vol. 106, No. 12: 391-400, June 16, 1959.
13. Campbell, J. -- Mandibular displacement. Dent. Practit., Vol. 5, No. 6: 175-190, Feb. 1955.

14. Carlsoo, Sven. -- Nervous co-ordination and mechanical function of the mandibular elevators. Acta. Odont. Scand., Vol. 10, Suppl. 11, 1952.
15. Farrel, J.H. -- The effect of mastication on the digestion of food, Brit. Dent. Jn., Vol. 100, No. 6: 149-155, March, 1956.
16. Gibbs, C.H., Messerman, T., Reswick, J.B., Derda, H.J. -- Functional movements of the mandible. Jn. Pros. Dent., Vol. 26, No. 6: 604-620, Dec. 1971.
17. Gillings, B.R.D., -- Photoelectric mandibulography. A technique for studying jaw movements. Jn. Pros. Dent., Vol. 17, No. 2: 109-121, Feb. 1967.
18. Griffen, C.J. -- Diagnosis and treatment of mandibular displacement by mandibular kinematography. The dentla nociceptive reflex. Aust. Dent. Jn., Vol. 8, No. 5: 384-397, Oct. 1963.
19. Hickey, J.C., et al. -- Mandibular Movements in three dimensions. Jn. Pros. Dent., Vol. 13, No. 1: 72-92, Jan, Feb. 1963.
20. Hildebrand, G.Y. -- Studies in the masticatory movements of the human lower jaw. Skand. Arch. Physiol., Vol. 61, Suppl. Berlin/Leipzig, 1931.
21. Ingervall, B. -- Recording of retruded positions of mandible in children. A comparison between registration in general anaesthesia and with children awake. Odont. Revy., Vol. 19, No. 4, 1968.
22. Ingervall, B. -- Relation between retruded contact, intercuspal and rest positions of the mandible in children with Angle class II Division 2. malocclusion. Odont. Revy., Vol. 19, No. 3, 1968.
23. Ismail, Y.H., George, W.A., Sassouni, V., and Scott, R.H. -- Cephalometric study of the changes occurring in the face height following prosthetic treatment. Part I. : Gradual reduction of both occlusal and rest face heights. Jn. Pros. Dent., Vol. 19, No. 4: 321-330, April, 1968

24. Ismail, Y.H., and Sassouni, V. -- Cephalometric study of changes occurring in the face height following prosthetic treatment. Part II : Variability in the rate of face height reduction. Jn. Pros. Dent., Vol. 19, No. 4: 331-337, April, 1968.
25. Jankelson, B., Hoffman, G.M., Henderson, J.A. -- The physiology of the stomatognathic system. Jn. A.D.A., Vol. 46, No. 4: 375-386, April, 1953.
26. Jerge, C.R. -- The neuromuscular mechanism underlying cyclic jaw movements. Jn. Pros. Dent., Vol. 14, No. 4: 667-681, July-Aug. 1964.
27. Kapur, K.K., Soman, S.D. -- Masticatory performance and efficiency in denture wearers. Jn. Pros. Dent., Vol. 14, No. 4: 687-694, July-Aug. 1964.
28. Kawamura, Y. -- Neuromuscular mechanisms of jaw and tongue movement. Jn. A.D.A., Vol. 62: 545-551, May, 1961.
29. Kawamura, Y. -- Recent concepts of the physiology of mastication. Advances in Oral Biology, Vol. 1: 77-109, 1964.
30. Knap, F.J., Richardson, B.L., and Bogstad, J. -- Motion of the mandible related to modern gnathologic concepts. Jn. Pros. Dent., Vol. 24, No. 2: 148-158, Aug. 1970.
31. Kurth, L.E. -- Mandibular movements in mastication. Jn. A.D.A., Vol. 29, No. 5: 1769-1790, Oct. 1942.
32. Moller, E. -- The chewing apparatus. Acta. Physiol. Scand., Vol. 69, Suppl. 280, 1966.
33. Murphy, T.R. -- The timing and mechanism of the human masticatory stroke. Arch. Oral. Biol., Vol. 10, : 981-993, 1965.
34. Neil, D.J. -- Variations in dietary habits with changing dentitions. Brit. Dent. Jn. 72-75, Jan. 1969.
35. Nemoto, K., Ishiwara, T., and Ai, M. -- A study on the three dimensional range of the mandibular movement at the incision inferius. Bull. Tokyo Med. Dent. Uni., Vol. 16: 123-137, 1969.

36. Newellwood, G. -- Centric occlusion, centric relation and mandibular posture. Jn. Pros. Dent., Vol. 20, No. 4: 292-306, Oct. 1968.
37. Oishi, S., Ishiwara, T., Ai. M. -- A study of the mandibular movements by means of the arm type motion analyzer and the condensor method. Bull. Tokyo Med. Dent. Uni. 15: 359-369, 1968.
38. Posselt, U. -- Studies in the mobility of human mandible. Acta. Odont. Scand., Vol. 10, Suppl. 10, 1952.
39. Posselt, U. -- Physiology of occlusion rehabilitation. 1962. Blackwell scientific publication, Oxford.
40. Posselt, U. -- Movement areas of the mandible. Jn. Pros. Dent., Vol. 17, No. 3: 375-385, May 1957.
41. Posselt, U. -- Range of movement of the mandible. Jn. A.D.A., Vol. 56, No. 1: 10-13, Jan. 1958.
42. Rudd, K.D., Morrow, R.M., Jendresen, M.D. -- Fluorescent photoanthropometry: A method for analyzing mandibular motion. Jn. Pros. Dent., Vol. 21, No. 5: 495-505, May, 1969.
43. Schweitzer, J.M. -- Masticatory function in man. Jn. Pros. Dent., Vol. 11, No. 4: 625-647, July-Aug. 1961.
44. Schweitzer, J.M. -- Masticatory function in man, mandibular repositioning. Jn. Pros. Dent., Vol. 12, No. 2: 262-291, March-April, 1962.
45. Shanahan, T.E.J., and Leff, A. -- Mandibular and articulator movements. Part II. Illusion of mandibular tracing. Jn. Pros. Dent., Vol. 12, No. 1: 82-85, Jan-Feb, 1962
46. Shanahan, T.E.J., and Leff, A. -- Mandibular and articulator movements. Part III. The mandibular axis dilemma. Jn. Pros. Dent., Vol. 12, No. 2: 292-297, March-April, 1962.
47. Shanahan, T.E.J., and Leff, A. -- Mandibular and articulator movements. Part IV. Mandibular three dimensional movement. Jn. Pros. Dent., Vol. 12, No. 4: 678-684, July-Aug. 1962.

48. Sherrington, C.S. -- "Selected writings of Sir Charles Sherrington"
BY: D.D. Brown. Hamish Hamilton Medical Books, London,
1939.
49. Sheppard, I.M. -- Denture occlusion. Jn. Pros. Dent., Vol. 20,
No. 4: 307-318, Oct. 1968.
50. Sheppard, I.M. -- The bracing position, centric occlusion and
centric relation. Jn. Pros. Dent., Vol. 9, No. 1: 11-20,
Jan-Feb. 1959.
51. Sheppard, I.M. -- Anteroposterior and posteroanterior movements
of the mandible and condylar centricity during function.
Jn. Pros. Dent., Vol. 21, No. 1: 86-93, Jan.-Feb. 1962.
52. Shepherd, R.W. -- A further report on mandibular movements.
Aust. Dent. Jn., Vol. 5, No. 6: 337-342, Dec. 1960.
53. Sheppard, I.M., Sheppard, S.M., and Rakoff, S. -- The mandibular
side shift and lateral excursions. Jn. Oral. Med.,
Vol. 22, No. 4: 115-118, Oct. 1967.
54. Sicher, H. -- Descriptive anatomy : The skull. Oral Anatomy.
C.V. Mosby company, St. Louis, 1960.
55. Sicher, H. -- Positions and movements of the mandible. Jn. A.D.A.,
Vol. 48, No. 6: 620-625, June 1954.
56. Silverman, M.M. -- Centric occlusion and jaw relations and fallacies
of current concepts. Jn. Pros. Dent., Vol. 7, No. 6:
750-769, Nov. 1957.
57. Sonstebo, H.R. -- C.E. Luce's recordings of mandibular movements
(1889). Jn. Pros. Dent., Vol. 11, No. 6: 1068-1073,
Nov.-Dec. 1961.
58. Storey, A.T. -- Sensory functions of the temporomandibular joint.
Jn. Canad. Dent. Ass., Vol. 34, No. 6: 294-300, 1968.
59. Swerdlow, H. -- Roentgen cephalometric study of vertical dimension
changes in immediate denture patients. Jn. Pros. Dent.,
Vol. 14, No. 4: 635-650, July-Aug. 1964.
60. Tallgren, A. -- Changes in adult face height due to ageing,
wear, and loss of teeth and prosthetic treatment. Acta.
Odont. Scand., Vol. 15, Suppl. 24: 1-112, 1957.

61. Tallgren, A. -- The reduction of face height of edentulous and partially edentulous subjects during long term denture wear. Acta. Odont. Scand., Vol. 24, 1966.
62. Thompson, J.R. -- Concepts regarding function of the stomatognathic system. Jn. A.D.A., Vol. 48, No. 6:625-637, June, 1954.
63. Woelfel, J.B. -- Electromyographic evidence supporting the mandibular hinge axis theory. Jn. Pros. Dent., Vol. 7, No. 3: 361-367, May, 1957.
64. Woelfel, J.B., Hickey, J.C., and Allison, M.L. -- Effect of posterior tooth form on jaw and denture movements. Jn. Pros. Dent., Vol. 12, No. 5: 922-939, Sep.-Oct. 1962.
65. Wood, G.N. -- Centric occlusion centric relation and the mandibular positions. Jn. Pros. Dent., Vol. 20, No. 4: 292-306, Oct. 1968.
66. Yurkstas, A.A., Emerson, W.H. -- Dietary selection of persons with natural and artificial teeth. Jn. Pros. Dent., Vol. 14, No. 4: 695-697, July-Aug. 1964.
67. Yurkstas, A.A. -- The masticatory act. Jn. Pros. Dent., Vol. 15, No. 2: 248-262, March-April, 1965.
68. The Reader's Digest Great Encyclopaedic Dictionary Vol. I.
69. Seitlin, D.J. -- The mandibular lever. Jn. Pros. Dent., Vol. 19, No. 4: 342-349, April, 1968.
70. Lee, R.L. -- Jaw movements engraved in solid plastic for articulator controls. Part I : Recording apparatus.
71. Graf, H., and Zander, H.A. -- Tooth contact patterns in mastication. Jn. Pros. Dent., Vol. 13, No. 6: 1055-1066, Nov.-Dec. 1963.
72. Beyron, H.L. -- Characteristics of functionally optimal occlusion and principles of occlusal rehabilitation. Jn. A.D.A., Vol. 48, No. 6: 648-655, June, 1954.
73. Granger, E.R. -- Functional relations of the stomatognathic system. Jn. A.D.A., Vol. 48, No. 6: 638-647, June, 1954.

74. Sheppard, S.M., and Sheppard, I.M. -- Incidence of lateral excursions during function with complete dentures. Jn. Pros. Dent., Vol. 26, No. 3: 258-268, Sep. 1971.
75. Shearer, P., Stallard, R.E, and Zander, H.A. -- Occlusal interferences and mastication. An electromyographic study. Jn. Pros. Dent., Vol. 17, No. 5: 438-449, May, 1967.
76. Butler, J.H. and Zander, H.A. -- Evaluation of two occlusal concepts. Parodn. Acad. Rev., Vol. 2, No. 1, March 1968.
77. Anderson, D.J. and Picton, D.C.A. -- Tooth contacts during chewing. Jn. Dent. Res., Vol. 36, No. 1: 21-26, Feb. 1957.
78. Ramfjord, S.P. -- The significance of recent research on occlusion for the teaching and practice of dentistry. Jn. Pros. Dent., Vol. 16, No. 1: 96-105, 1966.
79. Singer, -- Occlusion, functions and parafunctions. Int. Dent. Jn., Vol. 1, No. 3: 385-397, 1966.
80. Lammie, G.A., Perry, H.T., Crumm, B. -- Observations on a complete denture patient. Part III. Jn. Pros. Dent., Vol. 9, No. 1: 34-43, Jan.-Feb. 1959.