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A Three-Dimensional Cinefluorographic Analysis of Bolus Placement During Mastication

Joseph A. Ruscheinski
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A THREE-DIMENSIONAL CINEFLUOROGRAPHIC ANALYSIS OF BOLUS PLACEMENT DURING MASTICATION

by

JOSEPH A. RUSCHEINSKI

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF LOYOLA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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1973
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I will always be indebted to Drs. Donald C. Hilgers and James L. Jensen of the Orthodontic Department, and to Loyola University for the many doors they have opened for me.

I am most grateful to my parents for their moral and financial support which made my education possible.
AUTOBIOGRAPHY

Joseph Anthony Ruscheinski was born in Wrashkow, Czechoslovakia, on April 4, 1945.

He graduated from DePaul Academy in Chicago, Illinois, in 1963.

He attended Loyola University for two years, began his dental studies at Loyola University, and graduated in June, 1969.

He served as a Dental Officer in the United States Air Force from June, 1969, until June, 1971, while stationed in California and Alaska.

In June, 1971, he began his studies of Oral Biology and Orthodontics at Loyola University of Chicago.
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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

For all the volumes that have been written about restoration of decayed teeth, replacement of lost teeth, and the alignment of malopposed teeth, actually very little is known about mastication, the primary function of these structures. It has long been the practice of the dentist to restore occlusal surfaces to a maximal contact with opposing teeth and yet not interfere with excursive movements. The attempt is to maintain the ideal anatomic tooth form, number, and alignment to prevent any impairment of masticatory activity. It has been assumed that this combination will provide the patient with the best in function. Exactly what effect the loss of an intact dentition has on masticatory function is not entirely clear.

Pondering this question, investigators have fashioned tests for masticatory performance. The most logical and easily demonstrated test has been the diminution of food. However, investigators have been unable to agree as to the criteria for test foods and techniques. Moreover, no matter
what materials were used, they have been puzzled by the wide variation in performance among persons having the same numbers and types of teeth.

The role of bolus placement and management has been mentioned as playing a part in masticatory efficiency by several authors. This has been borne of the necessity of explaining the inadequacy of anatomic numbers to account for differences in masticatory performance. To date, no one has devised a method for studying bolus placement. With the use of image-intensifier cinefluorography, it has become possible to study internal motions of the body without undue radiation exposure. This study will determine the possibility of a three-dimensional analysis of bolus placement during mastication with the use of the cinefluorograph.
CHAPTER II
REVIEW OF THE LITERATURE

A. Mastication Efficiency

In attempting to determine the effect of normal chewing of food and the loss of ability to chew created by loss of teeth, investigations have taken many forms.

Among the first to document observations on the ability of subjects to reduce the particle sizes of various test foods were Lehman (1900) and Gaudenz (1901). Test foods included beef, macaroni, potato, and raw apple. Given amounts of these materials were chewed by subjects until there was a desire to swallow. The food was then collected and examined for particle size. Lehman observed the reduced portions were either in solution or were less than 2 mm particles. Gaudenz used a 1 mm sieve to separate his chewed particles. Subjects who were able to reduce the portions to a greater degree were graded as having a greater chewing efficiency.

In reviewing the literature of masticatory studies, Sognnaes (1941) observed that previous studies had neither been extensive enough nor sufficiently controlled to warrant
definite conclusions regarding either natural or artificial teeth.

In his article "The Masticatory Effect," Dahlberg (1942) describes the most thorough test and analysis of mastication until that time. Dahlberg noted the lack of a comparison between the physiology of normal teeth and defective sets of teeth. He saw a need for a satisfactory method and material for judging masticatory effectiveness. The material his subjects chewed was a cylindrical rod made of a 15 per cent gelatin, 5 per cent barium sulfate and red coloring matter. All this was hardened in formalin, then washed and cut into standardized portions. Following chewing, portions were washed through a tube of ten strainers with the diameter of the holes progressing in steps of 1 mm from 10 mm to 1 mm. Values for the surface area and volume of the chewed gelatin were used to compute a mastication coefficient, whose units represent sq cm ($cm^2$) of area per cubic cm of volume of the test portion. To minimize individual variability and to obtain a reliable mean, tests were run a total of ten times on each subject.

Sets of teeth were characterized by a "contact coefficient" which accounted for numbers and types of teeth and occlusal contacts. Using this "contact coefficient," sets of teeth were divided into four categories: extremely good, good, bad, extremely bad.

Using the methods that he worked out, he tested the
masticatory efficiency of people of different ages, sex, and sets of teeth, ranging from full complements to full dentures. Subjects were asked to chew until there was a desire to swallow. Interestingly, the decrease in mastication efficiency is rather small compared to the difference in contact coefficients from good to poor sets of teeth. This difference must be explained by the increased chewing skill and improved bolus management of the subjects as the dentition deteriorates. Regarding the number of chews among the subjects, those with poorer sets of teeth did not attempt to compensate by chewing a greater number of times. However, mastication coefficients showed a direct correlation to the number of chews. This means that those with impaired dentitions are willing to swallow larger particles. The correlation between contact coefficient and mastication coefficient is of the same order of magnitude as that between the number of chews and mastication coefficient.

In discussing what role variables played in his study, Dahlberg concluded that differences in chewing habits and differences in the quality of sets of teeth seemed to have equal parts in the masticatory effect. Other differences to consider are skill in chewing and anatomy of the teeth and jaws.

Yourkstas and Manly (1949) devised a method for measuring occlusal contact area. The subject is asked to register his bite into two layers of soft wax separated by cellophane. Effective area is measured by passing light through
the wax in a cylinder containing a light bulb and photovoltaic
cells at opposite ends. By blocking out areas, they were able
to compute the effect of missing teeth on the occlusal contact
areas of remaining teeth. Their study determined that of 44
patients with area differences between the two sides of the
mouth, 25 preferred to chew on the side with the greater area.
This method was suggested as a possible aid in predicting mas-
ticatory performance.

Manly and Braley (1950) devised a masticatory performance
and efficiency test which has since been used by other investi-
gators. The masticatory performance test is based on the per-
centage of masticated peanuts which will pass through a 10-mesh
screen after being subjected to 20 masticatory strokes. Masti-
catory efficiency was calculated from the number of chews re-
quired to reach a given degree of food pulverization. The per-
formance was found to be independent of the size of the mouth-
ful, provided that the number of chews was constant. Earlier
chewing was found to be random, while the process became more
selective for larger particles later. Efficiency dropped in
four categories ranging from complete sets of natural teeth to
full dentures.

Manly et al (1954) examined the masticatory function of
orthodontic patients having them chew portions of a soft food
for 20 masticatory strokes. Samples were recovered by a 10-
mesh screen and centrifugation. Chewing ability was found not
to be influenced by the presence of an orthodontic appliance, chewing on a preferred side, or the sex of the patient. Nor was there a change with age. The number of posterior teeth was found to have an important influence, ranging from the first premolar with the least value to the first molar with the greatest value. They also determined that a masticatory test using soft food is generally valuable to indicate chewing efficiency with all foods. Testing for pulverization at the time a patient is ready to swallow, patients with a low chewing efficiency show a willingness to swallow poorly pulverized food.

Hixon et al (1956) examined 1,573 young adults about to enter college and selected the 36 best occlusions to compare functionally with 55 malocclusions. They found a statistically significant difference in the chewing performance between the two groups.

Derksen et al (1959) used a pulverization-sieve collection test to determine the loss of chewing efficiency from natural to mutilated conditions in 6 subjects. They found little variation in repeated tests on individuals. Differences in chewing performance were not able to be explained only by the varying conditions of the subjects' dentitions.

Bascom (1962) used the Manly-Braley test to compare masticatory efficiency of patients with different types of denture teeth. The small number of patients did not allow any statistical analysis of the results.
Kapur and Soman (1964) used the Manly-Braley test to compare natural dentitions with those of artificial denture wearers. Since results showed that denture wearers were only one-sixth as efficient as those with all their natural teeth except third molars, their study proposed that a separate norm of efficiency be established for denture wearers.

Kapur et al (1965) used carrots and peanuts to determine the effect of occlusal markings, food platform area, occlusal inserts, and buccal and lingual contour on the chewing performance of 16 full denture wearers. While they found some small differences among these factors their evidence suggested to them that "the ability of the denture wearer to place and hold the food on the food platform during chewing is a more important factor for superior chewing with dentures than the mechanical cutting capacity of the chewing element." It appears that the chewing ability of the denture wearer is limited not because the artificial teeth are poor substitutes for natural teeth but because the food transportation apparatus becomes less effective.

Needham (1966) compared the chewing efficiency of porcelain vs. plastic teeth in full denture patients. He used various foods and recorded the subjective reactions of the patients in chewing with the two different sets of teeth.

In an article by Neill (1967), masticatory performance was expressed as the percentage volume of the masticated food
which passed through a 10-mesh sieve and the number of chews used to reach a swallowing threshold. All the subjects, with inter-arch gauges to measure occlusal contacts, were full-denture wearers. The results clearly showed a wide variation in the number of chewing strokes used from subject to subject. With regard to duration of contact, contact rate, number of chews per session and the duration of each sequence, there was no correlation between different subjects. There was no correlation between the masticatory performance of complete denture wearers and the number of chews required to reach a desire to swallow. These findings establish in full-denture wearers what Dahlberg established among subjects with natural dentitions. This would indicate that other factors must be considered.

Neill and Phillips (1970) tested 53 elderly male patients for masticatory efficiency. Of the 53, 36 wore full upper and lower dentures. Again, they found no relationship between chewing efficiency and number of chews. The quality of the dentures was assessed and performance was found to improve with the quality of the dentures.

Asha (1971) et al using a modified Manly-Braley test showed statistically that a balanced natural occlusion scored higher than a canine protected natural occlusion.

Markin (M.S. Thesis, 1972) attempted to determine whether early orthodontic procedures altered the masticatory
performance considering bolus size and chewing time. Markin's patients selected what they considered a normal mouthful of peanuts and chewed this amount until they were ready to swallow. The first test was run prior to placement of the orthodontic appliance and extraction of 4 bicuspid teeth, the second and third during active treatment. No significant difference relating to bolus size and chewing time was found between any of the three tests. An individual chews to a consistent particle size despite variables which confront him.

Studies of mastication using still and motion pictures were conducted by Schweitzer (1961). His purpose was to record the types and ranges of movement of the mandible, and with the aid of extra-oral tracing devices he was able to construct three-dimensional models of the movement of the lower incisor in function.

In what is certainly the most dramatic study of mastication, Syrop (1953) examined and filmed a 24 year old male who, as a result of surgery to remove a tumor, had a large opening on the left side of the face. Oral functions were able to be filmed through a clear, plastic prosthetic replacement for the lost structures. Syrop has been able to see the functions of many organs including the "strikingly mobile" tongue and the coordination of organs in chewing, swallowing, speaking, yawning, coughing, and smoking.
B. Cinefluorography

1. Cinefluorography Development

The term cinematography means the production of the illusion of motion with the aid of a motion picture. The term roentgen cinematography is used to describe x-ray motion pictures. Included under this classification are two basic methods; the direct and indirect. The direct method consists in exposing photographic plates in rapid succession. However, the mechanics involved in positioning and replacing the photographic plate in this technique limit the number of exposures per minute and make it impossible to study rapid movement. Indirect cinematography utilizing photographs of an image on a fluorescent screen is called cinefluorography. Cinefluorography has proven itself capable of studying a wide range of movements, from the relatively slow movements of the digestive tract to the extremely rapid movements of the tongue in speech. Mechanical, photographic, and electronic advances of this century have resulted in image intensifier cinefluorography, which is the most commonly used roentgen cinematography today. The image intensifier apparatus reduces the amount of radiation exposure to the patient in one minute to the range of several ordinary dental x-ray exposures. This is accomplished in three ways: 1) electronic acceleration of the image, 2) reduction in size of the image, and 3) pulse synchronization of the roentgen exposure with each individual motion picture frame exposure.
The last factor means that the patient is only exposed to radiation as long as each individual photographic frame is in place for an exposure. In addition to methods of viewing the film, exposures can also be monitored on a system utilizing a television screen.

Earlier studies such as that of MacIntyre in 1897 dealt mainly with direct cinematography. Warren and Bishop successfully employed cinefluorography in 1929, but the dramatic reduction in radiation exposure to the subject awaited the development of the workable image intensifier in 1953. The majority of the cinefluorographic research and clinical application dealt with the heart, urinary tract, digestive tract, cerebral circulation, and joint function. Other studies have dealt with the organs of speech, swallowing mechanisms, and mastication.

2. Methods of Quantitative Analysis

To date, to quantitatively analyze cinefluorographic data, analysis utilizing measurements must rely on both motion and single frame viewing. One method described by Berry and Hoffman (1959) was used to study the opening and closing of the condyle in relation to the glenoid fossa in temporo-mandibular joint movements. The viewing apparatus, equipped with a movable crosshair system, could locate points on a fixed motion picture frame and feed an X and Y reading into an electroplotter. The condyle was outlined by plotting eight points
on its perimeter. Repeating the same procedure for successive frames gave a picture of condylar movement. Image magnification was measured by placing a metal ball bearing above the joint examined. A 10 mm grid was superimposed on the image for image measurements. Commenting on the interpretation of the films, the authors state, "While detail is acceptable when the motion picture film is running, a stationary film gives a less sharp image. Homemade attempts at tracing presented quite a problem..." The authors were unable to determine whether apparent zig-zag lines in movement were a result of the inherent error of reading and plotting, or actual normal movement.

Sloan et al (1963) described an analysis for hyoid movement studies originally presented by Bench (1962). It consists of superimpositions of cephalometric tracings of fixed cranial landmarks over successive cinefluorographic images. The cephalometric analysis of hyoid position considers the following landmarks: a) cranial base (represented by the saddle angle, which is measured from nasion-sella turcica-basion, an indication of the relationship between the anterior and posterior cranial base, b) facial angle (the angle between Frankfort Horizontal and the facial plane, which represents maxillary and mandibular position in the antero-posterior direction), c) mandibular plane (plane of the lower border of the mandible), d) facial convexity (a measure of procumbency of jaws), e) facial height (linear measurement between nasion and menton), f) the
height of cervical vertebra 1-5, g) vertical height of the dens, h) distance from the hyoid bone to the mandible, i) distance of the hyoid bone to the genial tubercle, j) level of hyoid bone with respect to the cervical vertebrae, k) the distance of hyoid point to a vertical line drawn from the pterygoid root. Upon viewing cinefluorographic films, particularly when the frames are viewed on a stop-action frame-by-frame basis, it is readily apparent that these individual landmarks are not always able to be located with a great deal of accuracy. It is for this reason that Bench has sought to combine the desirable resolution properties of the cephalostat with the motion analysis made possible by the cinefluorograph. Motion of the hyoid bone is related to fixed cranial landmarks which are more easily identified on cephalostatic films. The technique requires corrections for magnification errors in both the cephalostatic and cinefluorographic systems. Finally, the hyoid movement on the cinefluorographic films can be shown on the cephalometric tracing.

Motion analysis is made possible by an apparatus such as the Vanguard Motion Analyzer. This allows the film to be viewed in motion or for an unlimited pause on a frame-by-frame basis. The unit magnifies the film size to the viewed image by a factor of 16.5, which is distortion free by 0.25 per cent. The projector has a micrometer readout from a crosshair system. X and Y readings are zero at the bottom left corner of the
screen. Crosshair positions are shown in dials which measure in inches, tenths, hundredths, and thousandths. The image can be shifted (1/16 inches) relative to the crosshair system to allow for individual frame variance. The motion analyzer can be coupled to automatic readout equipment which will activate IBM punch card and magnetic tape equipment for computer analysis.

3. Cinefluorographic Investigations

Cinefluorographic studies of the head and neck have been largely limited to investigations of speech, swallowing, and mandibular movement. Among the first to study swallowing patterns utilizing the cinefluorograph were Rushmer and Hedron (1951). Ramsey et al (1955) also employed cinefluorography to analyze deglutition. Straub (1962), Subtelny (1962), Cleall (1965), and Hedges et al (1965) have all investigated and attempted to define the normal and deviate swallow using the cinefluorograph. Moll (1960) and Shelton et al (1963) have used cinefluorography in studying speech.

Sloan et al (1967) reported on a cephalometric cinefluorographic comparison of orthodontic Class I and Class II malocclusion patients with regard to hyoid bone movement patterns, and found that their technique could validly be applied to this study. They concluded that there were two distinct hyoid patterns.

Cinefluorography was one method employed by Fink (M.S.
Thesis, 1968) to describe open-bite malocclusions. He found it a useful tool in diagnosing tongue and lip habits, as well as in charting hyoid bone patterns.

Wolk (M.S. Thesis, 1969) tested six patients for tongue thrust and EMG activity and cinefluorographically recorded several swallows before and after surgical mandibular resection. Wolk described three distinct hyoid bone patterns in swallowing.

Adran, Kemp, and Munz (1957) used lateral and postero-anterior cinefluorographic films to study the stability of full lower dentures in jaw and tongue excursions as well as chewing. Denture dislodging was determined by relating a metallic implant in the denture to the mandible.

In their article, "The Use of Cinefluorography in Dentistry" Boucher et al (1964) described a technique for studying temporomandibular joint movements. Noting the curvature of the articular eminence, their study attempted to determine whether or not the movement of the condyle in various excursions duplicated the curve of the eminence. Their study plotted the circumference of the condyle in relation to points on the articular eminence.

Sheppard and Sheppard (1968) related mandibular movements of edentulous patients to the position of the mandible during swallowing. Most mandibular movements were made to the swallowing position or slightly anterior to it.
In addition to these studies, several investigators have applied cineradiography to studies of mastication. Klatsky (1940, 1955) reported on a cinefluorographic study comparing the effort required in chewing stimulating and non-stimulating foods. He compared activity of the masticatory apparatus in chewing soft, non-fibrous foods and hard, bulky, fibrous foods. He described the chewing action as a subject with a full set of natural teeth, another with no lower posterior teeth, and a third with lower posterior teeth restored with a partial denture. In describing the mastication of the patient with no lower posterior teeth, Klatsky says: "We can readily see his abnormal chewing, the tongue constantly tossing the food to the anterior part of the mouth for the incisors and cuspids to do the grinding and chewing which is normally performed by the bicuspids and molars." Klatsky's brief account of the compensatory role of the tongue in controlling the bolus is one of the rare descriptions of the motions of the tongue as an aid to mastication found in the literature.

Sheppard (1965) sought to determine whether extreme vertical overlap of anterior teeth was associated with vertical masticatory strokes. He used lead markers to record the midline of the maxilla and mandible and observed the lateral deviation of the lower from the upper marker. This cinefluorographic study was limited to the postero-anterior projection.

Askew (1959) viewed the food distribution during
mastication of 60 subjects; 42 on static x-rays and 18 fluoroscopically, 13 of which were observed on a fluoroscopic screen and 5 on a projected cinefluorographic film. All his subjects were full-denture wearers. His study divided the areas into unilateral, bilateral, unilateral and bilateral, and anterior, as seen on a postero-anterior projection.

Adran and Kemp (1955) used eight-second cinefluorographic exposures in the lateral, postero-anterior, and ventrodorsal projections to study mastication. Subjects were not required to have full sets of natural teeth, only to claim to be able to chew satisfactorily. They observed a difference between munching and chewing in mastication and very little alteration of the chewing side in successive strokes. "Chewing" was confined mainly to the premolars and molar teeth. "Munching" was confined to the teeth anterior to the molars.

Sheppard (1968) compared the chewing habits of subjects with excellent occlusions, complete dentures, and those lacking all teeth. The projections were frontal and recordings were made of the location of the bolus as being left, right, center, and simultaneous bilateral.

Wictorin et al (1971) took cinefluorographic records of full-upper, partial-lower denture patients and full denture patients in both the postero-anterior and lateral projections. They divided the teeth into three areas in each of the views, and charted the frequency with which each area was used.
Twenty chews were recorded independently by five observers. No attempt was made to follow the position of the bolus between closures of the mandible. Rather, the position of the bolus was noted at the time of mandibular closure.
The cinefluorograph used in this study was a Picker model with a high gain image intensifying tube. The output phosphor had a diameter of nine inches and the input phosphor had a diameter of 0.8 inches. This gave a demagnification of 11:1 and a brightness gain of 3,000 to 5,000. The x-ray head and the image amplifier with the camera and optical system were mounted on each end of a "C" arm which was adjustable and capable of being locked in any vertical position so that the patient could be in a comfortable position. The cephalostat had only one side adjustable for maximum stability. The cephalostat was able to be rotated 90° to allow for both a lateral and a postero-anterior projection.

Before making films of patients, the cinefluorograph was checked for radiation output. Radiation hazard was given careful consideration before proceeding with this study. The following is the result of the test:
<table>
<thead>
<tr>
<th>KVP</th>
<th>mA</th>
<th>Frames/Sec</th>
<th>Roentgen/20 Sec</th>
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<td>90</td>
<td>13</td>
<td>60</td>
<td>0.50</td>
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</tr>
<tr>
<td>100</td>
<td>11</td>
<td>30</td>
<td>0.35</td>
</tr>
</tbody>
</table>

This places the radiation output per minute within the range of several ordinary periapical dental x-ray films. During the actual recordings, the subject wore a lead apron. The operator stood behind a lead-shielded screen, equipped with a leaded window. The window made it possible to view the chewing sequence on the fluoroscope at the same time that it was being filmed. In this way, the operator could shut off the radiation when the sequence of chewing was completed.

Kodak Shellburst 16 mm film was used for these recordings. The lens was set at f/2.8 and the focus at infinity. Tests were run at 100 KVP, 12 milliamperes and 60 frames per second.

This Picker Cinefluorograph has been tested for magnification and distortion using a spinning distortion wheel. A distortion measuring wheel which turned on an axle with concave ends was constructed of 1/8 inch plexiglass. Number nine lead shots were placed every 5 millimeters along the radius for a distance of 72 millimeters from the center of the wheel toward the periphery. The distortion wheel was placed in the cephalostat approximating the average patient midsagittal plane. The ear rod axis was adjusted to be concentric.
with the optical center of the image amplifier and the optical center of the amplifier was marked with a piece of lead taped to its surface. A cine record was made of the spinning wheel. When this image was projected and adjusted so that the distance between the center lead shot was 5 millimeters, then peripheral x-ray distortion could be computed by measuring the distance between the peripheral segments of lead shot anywhere in the image circle.

The cine record from the distortion wheel was projected and adjusted by means of the zoom lens so that the distance between the third and fourth lead shot was exactly five millimeters from center to center as measured with fine pointed dividers. The image of the first two lead shots was obliterated by the image of the axle of the distortion wheel.

The distance from the center of the third and the center of the most peripheral (fifteenth) lead shot was measured several times in all four quadrants of the circle. The average distance on the image was computed and compared to the actual distance between the third and fifteenth lead shot on the distortion wheel. The distortion from center to periphery (7 cm) was found to be eight per cent.

The subjects were seated in a contoured dental chair (Dental Eze Model) which is adjustable for height. The subjects were allowed to position the chair to a comfortable height. The subjects were then asked to assume a comfortable
head position into which they were then locked with ear rods. It was thought the unfamiliar sensation of the ear rods within the external auditory canal of the subject would result in a reluctance of the subject to move and thus maintain a stable head position. For the postero-anterior view, the cephalostat was rotated $90^\circ$ without changing the vertical height of the ear rods.

The bolus used was the lead backing of a standard Kodak dental film folded and rolled into a cylindrical shape so as to fit inside a Lilly #3 empty gelatin capsule.

A. Cinefluorographic Film Sequence

It was decided that subjects should have a full complement of teeth (third molars were not considered), good occlusion, and no history of trauma. Because of their familiarity with dental vocabulary, subjects were chosen from among dental students.

Before the cinefluorographic recording the subjects were given the sequence of positions through which they were to move the bolus. They were instructed not to rush through the sequence, but to move the bolus without delay and not to waste any motion. The sequence of positions is the following:

1. left canine-premolar area
2. right molar area
3. right canine-premolar area
4. left molar area
5. central incisors

The film began at position #1 and the patient was asked to tap twice on the capsule at this position before moving to the next. This was repeated for all the positions. Prior testing showed that the sequence took from eight to ten seconds.

Following the lateral exposure, the cephalostat was rotated 90° maintaining the same height and the sequence was repeated in a PA projection.

B. Film Analysis

The films were viewed on the Vanguard Motion Analyzer with its X and Y readout system. The tip of the maxillary central incisor was used in the lateral view and the midpoint of the incisal edges of the central incisor in the frontal view. From this common reference point, the position of the bolus was followed on each frame from the time the mandible dropped in one of the predetermined positions until it closed again at the next. This was repeated for the four movements in each of the two views.

The center of the stopped-in-movement bolus was located by the vertical-horizontal crosshair system of the Vanguard Analyzer. The position of the bolus, in terms of vertical (Y and Y') and horizontal (X and Z) axes, was represented and recorded as X and Y readings for the lateral view and Z and Y' for the frontal view.

Since the bolus was cylindrical, there were some
rotational and tumbling movements. These rotational movements were not considered, instead, the data represents only translatory movement.

Using the table of numbers obtained this way, the data was plotted on graphs. First, X, Y, Z, and Y' were individually plotted against time. The time interval between each of the readings, frames, and points on the graph represent 0.017 second. These plots are given in Appendix II.

For each of these distance against time plots, velocity at the time of maximum movement was determined (Table I). This velocity represents only the vertical vector of the velocity in the Y and Y' against time plots, and only the horizontal vector in the X and Z against time plots. It should be remembered that this velocity is a single-dimension vector in a three-dimensional movement. Velocities were not able to be determined in several of the axes because of the lack of consistent slope of movement.

The number of frames required to complete each movement was also recorded and the total time in seconds required for that movement from the time the jaws opened until they closed again is given in Table II.

Secondly, graphs were plotted to show the actual movement as seen in each of the views. This was done by plotting Y against X, and Y' against Z as they had been collected from the analyzer. Since there was often a delay before notable
movement of the bolus, every fifth frame, representing one 1/12 second, was plotted to avoid a cluster of points. To help relate the movement to the cranium, the tracing of the maxillary central incisors and first molars was superimposed on the points of movement of the bolus. These plots are given in Appendix I.
CHAPTER IV

RESULTS

A. General Considerations

Overall results of the eight movements recorded on each of the four subjects shows three stages in each movement. First, there is a period when the lower jaw drops and the tongue first locates and gains control of the bolus. This is confined to the area immediately adjacent to the teeth where the bolus originated. Second, there is a period of movement which gulfs the greatest part of the distance. Third, there is a period of placement of the bolus, usually immediately occlusal to the maxillary teeth on which the bolus is to be chewed next, as the lower jaw is raised to meet the upper. The last period involved a paralleling of the long axis of the bolus with the line of the cusps of the teeth. (Figure I)

By placing the vertical components of the two views of the same movement above one another, the two could easily be compared. Since the vertical axes Y and Y' would show a similar pattern or curve if the same movement in the lateral and frontal projection were similar or identical, the validity of
a three-dimensional mathematical analysis, obtained by breaking down both views to separate analyses of two axes at a time, would be established. In other words, if the vertical movement, which is common to both views, were alike in the lateral and the frontal graphs of Y against time and Y' against time, the actual movements could be considered alike. It was found that this was not the case. Although there was similarity, there was not enough in the vertical components of the two views to warrant a mathematical analysis incorporating both projections.

Further inspection of the data revealed a sustained slope in the two horizontal axes, X of the lateral view and Z of the frontal view, plotted against time. From these graphs it was possible to arrive at the maximum horizontal or vertical velocity achieved in the second stage of the bolus movement from one area to the next. These are recorded on Table I in millimeters per second.

The total number of frames or 1/60 seconds required for the bolus to move from one position to the next between successive closures of the mandible is recorded on Table II.

Since movement #1 to #2 and #3 to #4 are the same but involving opposite sides of the mouth, they may be considered to be comparable. Yet, in all except one of the eight movements, the second of the two in chronological order was completed in a shorter time. That is, it took a longer time to
move the bolus from the left canine-premolar to the right molar than it did to move the bolus from the right canine-premolar to the left molar.

B. Individual Subjects

Subject W.A. took a longer time to move the bolus between each of the positions than the remainder in the study in all but two of the eight recorded movements. In addition, his maximum velocities were slower than the other three subjects in all but one of the movements.

While this subject took longer and showed a slower maximum velocity than the other three subjects, he also showed a greater economy of movement in going from one position to the next. His movement in the vertical axis shows little deviation from a straight line between the two points. The range of maximum deviation from a straight line was 2.0 to 3.5 mm for the eight movements. Comparatively more time elapsed with the bolus in a relatively stationary position in this subject (range 0.10 to 0.97 seconds). In this more controlled type of movement there was little tendency to overshoot the next position.

J.C. showed a much wider range of movement than the other three subjects. Five of the eight movements showed maximum deviations greater than 8.5 mm. There was a great deal of vertical movement, both above and below the maxillary occlusal plane in moving between any two positions. There was a
tendency for the bolus to slightly pass the next position before it was placed between the teeth. This subject used less time in controlling the bolus in one position (0.033 to 0.25 seconds), and was rather direct in placing it between the teeth.

K.K. was not as direct in movement as W.A. and yet was not as variant as J.C. with respect to vertical movement. Maximum vertical deviations ranged from 2.0 to 6.5 mm. He also used a greater portion of the time in the first and third stages of the movements than J.C., spending more time to gain control and to place the bolus.

J.M. was similar to K.K. in that his vertical movement was relatively moderate in its deviation from a straight line between any two consecutive positions. All but one of the maximum deviations was between 1.0 and 6.0 mm. His time was more equally distributed among the three stages than the other subjects, meaning that he spent a relatively equal amount of time controlling, moving, then placing the bolus. Overall, J.M. spent the least total time in these four movements, utilizing about 38 per cent less time than W.A. who was the slowest of the sample.
FIGURE I

STAGES OF BOLUS MOVEMENT
LEFT MOLAR TO CENTRAL INCISOR
1/12 (0.084) SECOND INTERVALS

STAGE I: BOLUS CONTROL
STAGE II: BOLUS MOVEMENT
STAGE III: BOLUS PLACEMENT
<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>X</th>
<th>Y'</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>W.A.</strong></td>
<td>#1 to #2</td>
<td>88</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>2 to 3</td>
<td>190</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>3 to 4</td>
<td>80</td>
<td></td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>4 to 5</td>
<td>150</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td><strong>J.C.</strong></td>
<td>#1 to #2</td>
<td>210</td>
<td>150</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>2 to 3</td>
<td>120</td>
<td>96</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>3 to 4</td>
<td>150</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>4 to 5</td>
<td>180</td>
<td>290</td>
<td>180</td>
</tr>
<tr>
<td><strong>K.K.</strong></td>
<td>#1 to #2</td>
<td>98</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>2 to 3</td>
<td>170</td>
<td>90</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>3 to 4</td>
<td>170</td>
<td></td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>4 to 5</td>
<td>160</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td><strong>J.M.</strong></td>
<td>#1 to #2</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 to 3</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 to 4</td>
<td>180</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>4 to 5</td>
<td>210</td>
<td>210</td>
<td>220</td>
</tr>
</tbody>
</table>
# TABLE II

**TIME PER MOVEMENT IN SECONDS**

<table>
<thead>
<tr>
<th></th>
<th>LATERAL</th>
<th>FRONTAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>W.A.</strong></td>
<td>1.08</td>
<td>1.29</td>
<td>6.57</td>
</tr>
<tr>
<td>#1 to #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 to 3</td>
<td>0.60</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>3 to 4</td>
<td>0.90</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>4 to 5</td>
<td>0.72</td>
<td>0.62</td>
<td></td>
</tr>
</tbody>
</table>

| **J.C.** | 0.85 | 0.77 | 4.97 |
| #1 to #2 | | | |
| 2 to 3 | 0.40 | 0.43 | |
| 3 to 4 | 0.73 | 0.70 | |
| 4 to 5 | 0.73 | 0.35 | |

| **K.K.** | 0.90 | 1.27 | 5.90 |
| #1 to #2 | | | |
| 2 to 3 | 0.52 | 0.45 | |
| 3 to 4 | 0.68 | 0.68 | |
| 4 to 5 | 0.78 | 0.62 | |

| **J.M.** | 0.52 | 0.72 | 4.07 |
| #1 to #2 | | | |
| 2 to 3 | 0.27 | 0.43 | |
| 3 to 4 | 0.52 | 0.83 | |
| 4 to 5 | 0.48 | 0.30 | |
Investigators have studied mastication efficiency from several viewpoints. Many studies have been concerned with comparing the ability of subjects to pulverize food such as carrots or peanuts. Among the variables that have been subjected to research involving food pulverization are age, sex, number of teeth, number of chewing strokes, number of occlusal contacts, the presence or absence of artificial restorations, the configuration, composition, and number of denture teeth, the presence and absence of an orthodontic appliance, good occlusion vs. malocclusion, and the same patient from one performance to the next.

Dahlberg and Manly have determined that beyond the time that deciduous teeth have been replaced by permanent teeth, age is not a factor in chewing performance. Shiere and Manly determined, as did Dahlberg, that the sex of the patient had no bearing on masticatory performance. Dahlberg, Neill, Markin, and Allgood have determined that subjects do not compensate for defects in the masticatory anatomy by chewing a longer
time, yet they chew to a consistent particle size from one test to the next. Those with defective dentitions show a willingness to swallow larger particles. Hixon has shown that subjects with good occlusions perform significantly better than subjects with malocclusions.

As Dahlberg determined, and later investigators verified, "contact coefficients" or contacts between maxillary and mandibular teeth are the best indicators in predicting chewing performance. Yet the decrease in masticatory performance is small compared to "contact coefficients" from good to poor sets of teeth or dentures. Kapur, who determined the effect of occlusal markings, food platform area, occlusal inserts, and buccal and lingual contour of teeth on the masticatory performance of artificial denture wearers, concluded that the ability of the denture wearer to hold and control the bolus was the important factor in superior chewing ability rather than the mechanical cutting element. Neill has confirmed in denture-wearers the conclusions that Dahlberg reached with regard to natural dentitions, that anatomic numbers cannot be used to predict masticatory performance.

The habitual chewing pattern of a subject has been shown to be critical in tests of chewing performance. Dahlberg was the first to mention this. He said that individuals have different chewing habits and that the chewing results obtained were dependent upon individual habit. An individual is
relatively consistent when tested for swallowing threshold on repeated tests, although large differences exist among individuals. An individual chews to a characteristic particle size despite the variables with which he may be confronted.

Dahlberg, Kapur, and Neill list the role of increased skill in bolus placement and management as a compensatory mechanism in those with poorer sets of teeth. Klatsky, in his cinefluorographic study of mastication, describes the chewing pattern of a subject without posterior teeth. The tongue was constantly tossing food to the anterior part of the mouth for the incisors and canines to perform the chewing normally done by the posterior teeth.

While the teeth, palate, lower jaw, and facial musculature certainly aid in managing the bolus, the tongue is the chief agent of bolus movement and placement. It is possible then that the increased use and skill of the tongue may be the equalizing factor that allows a person with a poorer dentition to approach the mastication efficiency of a person with a better dentition. Hedges has stated, "It would appear that the tongue is the most important organ in compensating for oral deficiencies and it can take up the function of the other abnormal parts of the mouth." The advent of image intensifier cinefluorography has made it possible to study bolus movement with a minimum of interference.

To date, tongue patterns have not been studied with
respect to mastication. The bulk of research in tongue movements is found in speech literature regarding speech defects, and orthodontic literature regarding normal and abnormal deglutition. Habitual deviation from the normal in function and functional adaptation are the gist of such studies. Problems in speech and swallowing have been shown to be related to tongue patterns. Researchers in speech and orthodontics have studied tongue movements and positions for various sounds using both conventional cinematography and lateral cinefluorographic films. Blyth (1959) has classified lisps on the basis of conventional cinematographic films and static x-rays, relating types of open-bite to tongue position in speech. Tulley (1960), using cinefluorography, showed a difference in tongue patterns between Class I and Class II Division I malocclusion subjects in their pronunciation of "sing a song of sixpence," and in swallowing.

Kirkpatrick and Olmsted have cinefluorographically documented the compensatory swallowing pattern of cleft palate patients where it has not been possible to effect a velopharyngeal closure. During swallowing, the tongue tends to rise posteriorly in a mound or hump, more than in the normal, to raise the palate.

Further evidence of patterns in tongue movements has been documented cinefluorographically by Shelton, who measured tongue height in repeated phonations, on a frame-by-frame
basis. Graphs of the measurements against time showed that patterns in the individual were consistent and that there was a consistency among different individuals.

Using a Cephalometric-cinefluorographic superimposition technique, Cleall showed that adolescents have a characteristic and reproducible movement pattern of oropharyngeal structures in swallowing. There are marked differences in these patterns between a normal sample, a Class II group, and a tongue thrust sample. Cleall generalizes that positions and positional changes that occur during deglutition are largely in accord with the dictates set by the local skeletodental configuration. This conclusion was reinforced by the results of a tongue-crib experiment. Cinefluorographic records were taken before placement of a tongue-crib, immediately after placement, six months after placement, upon removal, and two months following removal. The crib experiment showed that it was possible to cause rapid modification of the movements of glossopharyngeal structures during swallowing. The fact that these modifications were reversed upon removal of the tongue-crib further supports the contention that the tongue adapts to the needs and requirements of the individual.

Considering the evidence of the pattern of movement that has been observed in tongue movement involved in speech and swallowing, it becomes reasonable to hypothesize that tongue patterns may be evident in mastication. Furthermore, the
adaptability of the tongue to the situation in which it finds itself, be it cleft palate or tongue-crib, lends weight to the concept of its adaptive role in the masticatory compensation for a mutilated dentition.

It would be useful to determine whether patterns of movement exist in habits of chewing. This present study sought to determine the feasibility of a three-dimensional analysis of bolus placement. Patterns of bolus movement would reflect patterns of tongue movement. The great majority of cinefluorographic evidence in speech and swallowing has been gathered in two-dimensional lateral views only. However, because lateral films cannot discriminate between left and right sides of the mouth, they are useful primarily in events occurring in the midline of the mouth. A frontal view is also necessary for a meaningful study of bolus placement. Ideally, a cinefluorograph would record the bolus movements simultaneously in the lateral and frontal projections. But, since no such cinefluorograph has been constructed, this was not possible.

Were such a cinefluorograph available, the location of the bolus in space and time could be plotted on a three-dimensional graph. Since the vertical axes or movement of these two views would be the same movement, the two views would be related by this common factor. Plotting of this graph would show a curve for movement which would portray all three dimensions of the movement of the bolus.
The question arose whether there would be enough similarity in the vertical components of two successive movements, one in the lateral view, another in the frontal view, to justify the assumption that they were identical for purposes of three-dimensional plotting. This would allow movements to be compared on a three-dimensional basis. While there was a great deal of similarity in the lateral and frontal views, vertical movement, as plotted against time, was generally too different, in the same or between different movements, to allow this assumption.

From the radiation output of the cinefluorograph, it is evident that the total radiation received by each of the subjects in this experiment was no more than that received in several ordinary dental periapical films. The maximum radiation exposure to each of the subjects was approximately twenty seconds. This places the total amount of radiation in the range of 0.5 R. This low radiation level allowed the experiment to proceed with the confidence that no hazard was being posed to the subjects.

Location of anatomic radiographic landmarks proved to be a problem, not so much in the lateral view as the frontal view. Berry and Hoffman (1959) were unable to trace individual frames and commented that detail was acceptable only while the film was in motion. This is despite the fact that their cepholostat was angulated for a better view of the
object of their study, the TMJ. They were unable to determine whether apparent zig-zag lines in movement were a result of the inherent error of reading and plotting, or actual movement. Bench has utilized cepholostatic tracings superimposed on cine-fluorographic projections, but this contains errors of magnification and superimposition.

For this study, the movement of the bolus was charted in relation to a readily located cranial landmark, the tip of the maxillary central incisor in the lateral view, and the midpoint of the tips of the maxillary central incisors in the frontal view. This proved to be a stable reference point for three reasons:

1. the normal stability of the cranial structures during mastication,
2. the maintaining of the same subject-selected vertical height of the chair and ear rods for both views, and
3. the reluctance of the subject to move because of the pressure of the cephalostatic ear rods in any lateral or vertical movement of the head.

In fact, when the reference point was recorded at the beginning of each movement, the greatest deviation was found to be .02 inches. This is a 0.5 mm error. Without this stability of the head and the availability of the maxillary central incisor as a landmark, it would not have been possible to verify that these movements were of the bolus alone, not of the bolus and
The results of this study have shown that it is convenient to describe bolus movement as occurring in three stages. The first is the action required by the tongue to gain control of the bolus as the mandible separates from the maxilla. In this stage, some slight movement is observed as the bolus is moved toward the midline. Here, there is generally a pause in the movement. In two of the subjects, K.K. and J.M., this pause was moderate in length (0.033 to 0.50 seconds and 0.10 to 0.35 seconds respectively). In W.A. this pause was generally longer (0.10 to 0.97 seconds), while in J.C. the pause was of a shorter duration (0.033 to 0.20 seconds).

The second stage of bolus movement consisted of a period of rapid movement which spanned the greater part of the distance to be covered. Maximum velocities for this movement in any one direction were able to be calculated where there was enough of a slope to make a reasonable determination. For the vertical axes, the velocities ranged from 60 to 210 mm per second. For the two horizontal axes, the velocities ranged from 75 to 290 mm per second. These maximum velocities were taken from the graphs where there was rather rapid movement over distance of at least 5 millimeters. The amount of vertical deviation from a straight line between any two positions was observed to be minimal in W.A. (2.0 to 3.5 mm
maximum). On the other hand, J.C. presented a wide range of vertical movement (five of the eight measurements 8.5 mm or greater). K.K. and J.M. showed a moderate range of vertical movement (2.0 to 6.5 mm and all but one 1.0 to 6.0, respectively). The total time elapsed in this second stage varied from 0.15 to 0.32 seconds for W.A., 0.12 to 0.48 for J.C. and 0.083 to 0.38 for both K.K. and J.M. Here W.A. required a more consistent time in his more controlled movement.

The third stage is similar to the first except that it is the reverse. The bolus is stopped occlusal and lingual to its destination for a pause. Here, the bolus is rotated to fit lengthwise between the teeth. It is then placed between the teeth as the mandible closes. The range of time required for W.A. to place the bolus was 0.05 to 0.47 seconds. J.C. and K.K. required 0.083 to 0.35 and 0.17 to 0.37, respectively. J.M. who was the fastest considering all movements took 0.067 to 0.22 seconds.

Comparing the movements from the canine-premolar area to the molar area of the opposite side of the mouth, the succeeding was accomplished in a shorter time in six of the eight movements, i.e. it was moved faster from the right canine-premolar area to the left molar area than from the left canine-premolar area to the right molar area. This may indicate an increasing familiarity with the bolus in succeeding movements, or may be related to predominant left-or-right-sided chewing
by the subjects.

W.A. may be said to be a distinct type in bolus manage-
ment in his overall slow pace of movement. His vertical move-
ment was distinctly limited when compared to the others. While
these tendencies have been gathered from the data, a larger
sample is needed before a meaningful categorization can be
attempted.

Differences observed may have been influenced by a num-
ber of factors. While every effort was made to ensure that the
subject was in a comfortable position, both on the chair and
in the manner in which he held his head, head position may have
had an effect on the ability to move the bolus. Another fac-
tor to be considered is the patient's attitude toward the radia-
tion exposure. In selecting subjects, the experiment was ex-
plained in terms of procedure and radiation dose. If the pro-
spective subject expressed a reluctance to participate, he was
considered unsuitable. Nevertheless, this radiation - con-
scious group could differ in their haste to finish the se-
quence. Ability to follow directions may also be considered
a factor in the experiment.

Radial distortion in the cinefluorograph-analyzer ap-
paratus has been measured to be eight per cent over a radius
of seven centimeters. Since all the bolus movement occurred
in only half that range, the error in measurement can be con-
sidered to be less than half.
Overall, this study has shown that it is possible to study bolus movement and placement on a quantitative basis. Bolus position can be followed on a frame-by-frame basis or in motion. The bolus can be followed in both views, quite easily in the lateral view, with some effort in the frontal view. Since the anatomic landmarks, particularly in the frontal view, are too indistinct for tracing purposes, the tip of the maxillary central incisor can be a useful landmark in relating the two views.

A cinefluorographic apparatus which would enable bolus movements to be recorded laterally and frontally in synchrony would permit plotting of the movement on a three-dimensional coordinate system. The two vertical axes would be identical in dimension and time and would relate the horizontal axes of the frontal and the lateral views. Using a larger sample, subjects can be compared to see whether there are differences in the levels of skill of bolus management. It would be interesting to see in which of the three stages individuals would show the greatest differences. Generally, movements over greater distances can more readily be compared to one another.
CHAPTER VI
SUMMARY AND CONCLUSIONS

Investigators studying mastication efficiency have been unable to account for the fact that some individuals with poor dentitions can perform chewing tests nearly as well as those with intact dentitions. The importance of the ability to place food between remaining teeth has been mentioned in the literature, but bolus placement has never been directly studied.

Cinefluorographic films were taken of four subjects as they moved a radiographic bolus through a predetermined sequence in the mouth, first in a lateral, then in a frontal view.

Bolus position was charted on each individual frame using a Vanguard Motion Analyzer. This study showed the following:

1. The position of the bolus was able to be located for each frame in both views.

2. Under the conditions of this experiment, the maxillary central incisor was a useful and stable reference point
for relating the two views.

3. Comparison of lateral and frontal views did show a great deal of similarity but not enough to allow a three-dimensional plotting of the data.

4. Bolus movement from one position to another can be divided into three stages:
   a. the action of the tongue gaining control of the bolus,
   b. movement to a location approximating the next destination; it is during this stage that maximum velocity is reached,
   c. placement of the bolus between the teeth.

5. Maximum velocities along any given dimension can be determined for bolus movements.

6. Simultaneous recording of the lateral and frontal view would allow three-dimensional plotting of bolus movement.
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APPENDIX I

BOLUS MOVEMENT IN LATERAL AND FRONTAL VIEWS
W.A. #1 to #2
LEFT CANINE-PREMOLAR TO RIGHT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.C. #1 to #2
LEFT CANINE-PREMOLAR TO RIGHT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
K.K. #1 to #2
LEFT CANINE-PREMOLAR TO RIGHT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.M. #1 to #2
LEFT CANINE-PREMOLAR TO RIGHT MOLAR
1/12 SECOND INTERVALS

(83 MILLISECONDS)
W.A. #2 to #3
RIGHT MOLAR TO RIGHT CANINE-PREMOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.C. #2 to #3
RIGHT MOLAR TO RIGHT CANINE-PREMOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
K.K. #2 to #3
RIGHT MOLAR TO RIGHT CANINE-PREMOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.M. #2 to #3
RIGHT MOLAR TO RIGHT CANINE-PREMOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
W.A. #3 to #4
RIGHT CANINE-PREMOLAR TO LEFT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.C. #3 to #4
RIGHT CANINE-PREMOLAR TO LEFT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
K.K. #3 to #4
RIGHT CANINE-PREMOLAR TO LEFT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.M. #3 to #4
RIGHT CANINE-PREMOLAR TO LEFT MOLAR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
W.A. #4 to #5
LEFT MOLAR TO CENTRAL INCISOR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.C. #4 to #5
LEFT MOLAR TO CENTRAL INCISOR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
K.K. #4 to #5
LEFT MOLAR TO CENTRAL INCISOR
1/12 SECOND INTERVALS
(83 MILLISECONDS)
J.M. #4 to #5
LEFT MOLAR TO CENTRAL INCISOR
1/12 SECOND INTERVALS

(83 MILLISECONDS)
APPENDIX II

VERTICAL AND HORIZONTAL AXES OF BOLUS MOVEMENT

PLOTTED AGAINST TIME IN MILLISECONDS
W.A. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR

LATERAL VIEW

\[ Y \text{ in mm} \]

\[ t \text{ in milliseconds} \]

\[ X \text{ in mm} \]

\[ t \text{ in milliseconds} \]
W.A. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR
FRONTAL VIEW

\[ y' \text{ in mm} \]

\[ z \text{ in mm} \]

\[ t \text{ IN MILLISECONDS} \]
W.A. #2 to #3
RIGHT MOLAR TO RIGHT CANINE - PREMOLAR
LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]
W.A. #3 to #4

RIGHT CANINE - PREMOLAR TO LEFT MOLAR

LATERAL VIEW

\[
\begin{array}{c|c|c}
\theta & 50 & 40 & 30 & 20 & 10 \\
\hline
\text{mm} & 250 & 500 & 750 & 500 & 750 \\
\end{array}
\]

\[ t \text{ IN MILLISECONDS} \]

FRONTAL VIEW

\[
\begin{array}{c|c|c}
\theta' & 50 & 40 & 30 & 20 & 10 \\
\hline
\text{mm} & 250 & 500 & 750 & 500 \\
\end{array}
\]

\[ t \text{ IN MILLISECONDS} \]
W.A. #4 to #5

LEFT MOLAR TO CENTRAL INCISOR

LATERAL VIEW

Y in mm

X

250 500 750

250 500

FRONTAL VIEW

Y' in mm

Z

250 500

t IN MILLISECONDS

250 500 750

t IN MILLISECONDS
J.C. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]

\[ y, y', z \text{ in mm} \]
J.C. #2 to #3

RIGHT MOLAR TO RIGHT CANINE - PREMOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]
J.C. #3 to #4

RIGHT CANINE - PREMOLAR TO LEFT MOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]
J.C. #4 to #5

LEFT MOLAR TO CENTRAL INCISOR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]

\[ t \text{ IN MILLISECONDS} \]
K.K. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR

LATERAL VIEW

$Y$ in mm

$X$ in millimeters

$t$ in milliseconds
K.K. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR
FRONTAL VIEW

\[ y' \text{ in mm} \]

\[ z \text{ in mm} \]

\[ t \text{ in milliseconds} \]
K.K. #2 to #3

RIGHT MOLAR TO RIGHT CANINE - PREMOLAR

LATERAL VIEW

\[ \begin{align*}
\text{Y in mm} & \quad 50 \quad 40 \quad 30 \quad 20 \quad 10 \\
250 \quad 500
\end{align*} \]

\[ \begin{align*}
\text{X in mm} & \quad 50 \quad 40 \quad 30 \quad 20 \quad 10 \\
250 \quad 500
\end{align*} \]

\( t \) IN MILLISECONDS

FRONTAL VIEW

\[ \begin{align*}
\text{Y' in mm} & \quad 50 \quad 40 \quad 30 \quad 20 \quad 10 \\
250 \quad 500
\end{align*} \]

\[ \begin{align*}
\text{Z in mm} & \quad 50 \quad 40 \quad 30 \quad 20 \quad 10 \\
250 \quad 500
\end{align*} \]

\( t \) IN MILLISECONDS
K.K. #3 to #4

RIGHT CANINE - PREMOLAR TO LEFT MOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]
K.K. #4 to #5

LEFT MOLAR TO CENTRAL INCISOR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILISECONDS} \]

\[ t \text{ IN MILISECONDS} \]
J.M. #1 to #2

LEFT CANINE - PREMOLAR TO RIGHT MOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]
J.M. #2 to #3
RIGHT MOLAR TO RIGHT CANINE - PREMOLAR
LATERAL VIEW

FRONTAL VIEW

t IN MILLISECONDS
J.M. #3 to #4

RIGHT CANINE - PREMOLAR TO LEFT MOLAR

LATERAL VIEW

FRONTAL VIEW

\[ t \text{ IN MILLISECONDS} \]

\[ y \text{ in mm} \]

\[ x \text{ in mm} \]

\[ z \text{ in mm} \]

\[ t \text{ IN MILLISECONDS} \]
J.M. #4 to #5
LEFT MOLAR TO CENTRAL INCISOR
LATERAL VIEW

FRONTAL VIEW
The thesis submitted by Dr. Joseph A. Ruscheinski has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May 17, 1973
Date

Signature of Advisor