Predictive Measures of Tooth/Tooth Contact in Mastication

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APPROVED

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Abstract

Understanding the process of mastication, or chewing, is very important in humans. Understanding the way people chew can help craniofacial repair to victims of accidents or other conditions. Stages of chewing and swallowing have been categorized; however, it is currently unknown when exactly the teeth meet during mastication. Vertical motion data were obtained from seven subjects while chewing food of different consistencies. A videofluorograph collected the data and they were manipulated in Excel to be plotted as time vs. vertical displacement for the upper incisor tooth. The first and second derivatives of these motion-time charts were taken in order to determine velocity and acceleration with respect to time. These data were analyzed to determine specific times of heightened acceleration and velocity. Due to the limited sampling rate acceleration data were too noisy to be used. Velocity was found to be greatest at both maximum and mid-gape. No trends were evident to show a predictive time of when teeth meet during the jaw-closing process.

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Advice to Future Honors Students

An honors thesis is an excellent way for students to take what they have learned in their Syracuse University classes and apply it to the outside world. Choose a project topic that interests you, something you will enjoy putting time into exploring on a deeper level.

It is a good idea to consult various faculty members both in and outside of your major for advice when carrying out your project. It is important to have your written thesis be understandable to all readers, even the ones outside your area of study. It is also smart to consult the faculty and staff at the Honors Program; they are always available and willing to help.

Before you carry out your project you should make a timeline—and follow it seriously throughout your junior and senior years. As in any project, it is very easy to get behind. Try to start your thesis work as early as possible and work on it constantly throughout the semester, instead of cramming it into spring break and the final weeks before the due date. Your thesis project is a challenge, but through planning and diligent work, it can be very rewarding as well.

Acknowledgements

I would like to express my gratitude to the following people for their support in helping me carry out my honors thesis project. First of all I would like to thank my advisor, Dr. Karen Hiiemae, Professor of Biomedical and Chemical Engineering, who helped make my thesis project not only challenging and educational but also a fun experience. She and Dr. Jeffrey Palmer, from Johns Hopkins University, provided me with the data I used for the extensive analysis. Dr. Bruce Carter, from the College of Human Services and Health Professions, has provided excellent guidance for my thesis planning during HNR 309 my junior year. Next, I would like to thank Chris Stathatos from the Institute of Sensory Research for his assistance in computer-related issues. Amit Vaish, at Penn State University, is very knowledgeable about the DaDisp program I used for analysis and has helped me with the software-related difficulties I encountered. Henry Jankiewicz, the Honors Program Writing Consultant, has helped me improve my writing skills by instructing me in Writing 209 and also has edited my thesis drafts and provided insightful comments. Last but certainly not least, I would like to thank Dr. Gustav Engbretson, chairman of the Department of Biomedical and Chemical Engineering, for taking the time to read my honors thesis as my second reader and also for being an outstanding mentor during my four years at Syracuse University.

Introduction

The act of chewing, known in technical terms as mastication, is the first step in the digestion of food. Food must be broken down into smaller pieces in order for it to form a bolus (mass of food), which will slide down the throat to the stomach through the pyloric sphincter. Thus, the mechanical aspect of digestion takes place in the mouth. There is also a chemical process that occurs in the mouth that aids in digestion. Salivary amylase, an enzyme, is secreted when food is about to be eaten. This project will focus on the mechanical aspect of digestion that occurs in the mouth.

The orofacial complex is the mechanism used in feeding, speech, and breathing. Studying this system can provide valuable information that can serve several purposes. People who suffer strokes often have difficulties eating and talking. It can be useful in craniofacial repair that is needed for victims who have been injured in accidents. Also, burn victims that have damaged nerve endings can lose control of sensory input to the muscles of the face and jaws. It is important to understand how these mechanisms work, so they can be repaired when damaged. Many different professional communities, both clinical and those involved in basic research, can also benefit from orofacial research.

Previous research on human jaw movements in mastication has largely relied on external measurement of jaw movement. One such method of externally recording data movement is by using a Sirognathograph. A Sirognathograph is a device used to measure movements in the X, Y, and Z directions of a small magnet fixed to the lower central incisors. These movements can be recorded with respect to time (see Figure 1). This method has helped researchers determine relationships between chewing patterns in foods of different consistencies such as apple, banana, and cookie (Hiiemae & Palmer, 1999). One way to do this is to compare the chew/swallow ratio, the number of chews before each swallow. While external measurements are helpful in calculating the time of certain movements, it cannot visually show where the tongue, bolus, and teeth are with respect to time.

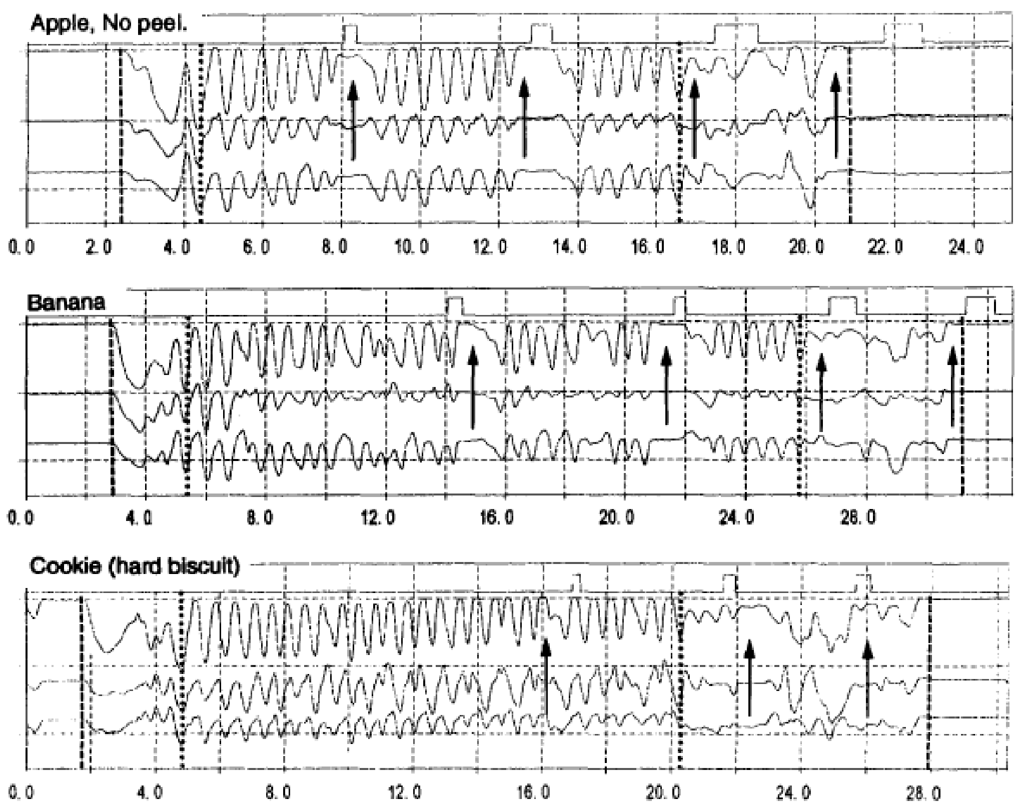


Figure 1: Sirognathograph recordings for one individual chewing three different types of food with respect to time. Each type of food has three line graphs: the top represents vertical displacement, the middle represents lateral jaw movement, and the bottom represents anteroposterior movement. The arrows indicate times of swallowing (Hiiemae et al., 1996).

Tongue movements have also been explored not only in feeding but also in speech (Hiiemae & Palmer, 2003). Hiiemae, Hayenga, and Reese (1994) linked jaw movement in opening to the reversing movements of the anterior tongue segment in the macaque. Hori, Ono, and Nokubi (2006) measured tongue pressure, finding a maximum near the beginning of the mouth opening. Tongue pressure reached zero during jaw opening, and pressure then increased as chewing progressed.

The method of videofluorography (VFG) allows us to see a more internal view of mouth movements during feeding and speech. A VFG tape is essentially a moving x-ray picture of a subject chewing, with a timestamp in the corner of the screen (See Figure 2). It can visually show where the tongue, bolus, and teeth are with respect to time. However, this method also has its limitations. The various movements inside the mouth do not appear clear-cut when one is watching the tape. As a result, when looking at these tapes, one cannot tell *exactly* where or when the teeth come into occlusal contact—but can obtain a logical guess.

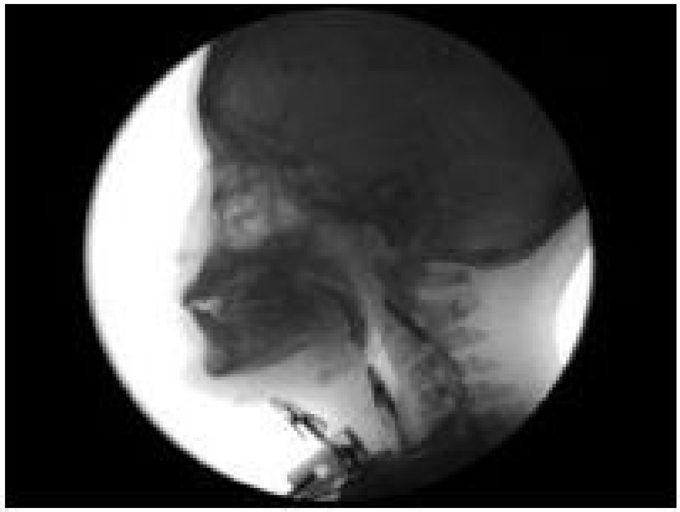


Figure 2: One frame from VFG, focusing on the jaw and throat.

As mentioned earlier, external data measurements can only show what is happening outside of the jaw, and the method of VFG can visualize the motions of the tongue, bolus, and teeth. However, not one of these methods can show a specific indication of the time of tooth/tooth contact. This is where the concepts of velocity and acceleration come into play. When the teeth meet, there is a decrease in slope in the vertical displacement graph. See Figure 3.

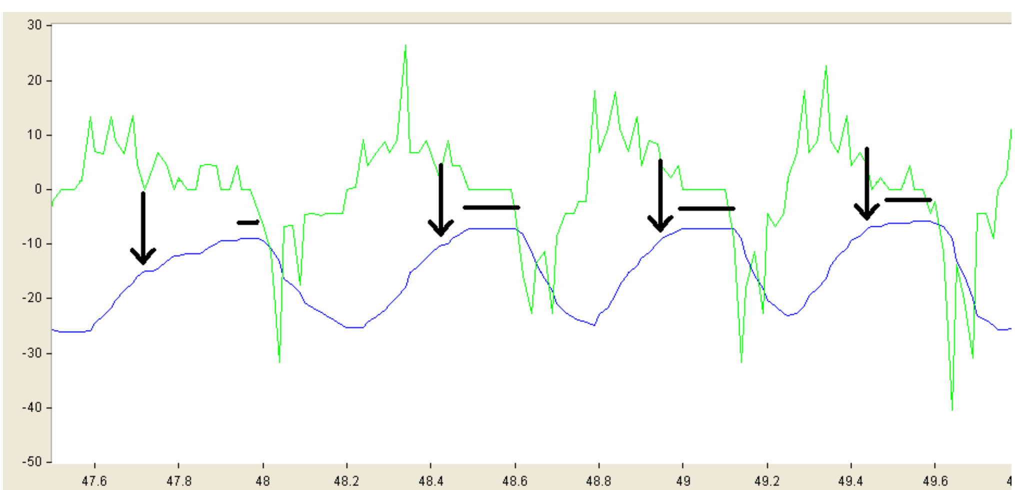


Figure 3: Four consecutive cycles of a female subject eating cookie. The blue line represents vertical displacement and the green line shows velocity. Arrows mark the

time of predicted *tft* contact and the horizontal bars mark the period of predicted lateromedial movement in occlusion. Data from VFG recording.

General physics notes that a decrease in positive slope in a displacement graph is equal to a decrease in velocity. If velocity could be calculated from the displacement data, the times of decreased velocity should indicate a time of contact.

Because these data can be analyzed with respect to time, it is evident in the displacement graphs when there is resistance to the motion of the jaw. When the jaw is closing on a bolus of food, it is going to meet resistance when both rows of teeth meet the food. This point of contact is called tooth/food/tooth contact, or *tft* contact, and will be the parameter of interest in this paper. As the food is broken up in the mouth, the time between *tft* contact and maximum occlusion should decrease.

This decrease in movement with respect to time should show a decrease in velocity and a decrease in acceleration. If times are pinpointed in each chew cycle that show these changes, they can be compared to the video fluorography tapes to visually see if the teeth are in contact at these times. Then, a general relationship might be able to be established that can predict the time of *tft* contact.

The goal of this project is to determine if there is a predictive measure of *tft* contact in human feeding. Ultimately, the goal of my research will be to formulate a second-order differential equation that will model the displacement of the jaw over time. Previously acquired mastication data from seven subjects will be used to formulate this equation, courtesy of Dr. Karen

Hiiemae and Dr. Jeffrey Palmer. Each subject chewed hard food and soft food. The hard food was a cookie and the soft food was a banana. These data will be analyzed in both Microsoft Excel and DaDisp.

I will compare these Excel data to previously acquired data that were collected via videofluography (VFG). It should be noted that the Excel data were derived from the original VFG data. The VFG data can then be compared with the equation for tooth-tooth contact to determine if the time that the teeth are in contact as modeled in Excel is the same that they are in contact in the videotape.

Background

In order to fully grasp the process of mastication, it is important to understand the anatomy of the human mouth. The human mouth is framed by the mandible (jaw), which articulates with the mandibular fossa on the temporal bone of the skull and the upper jaw. The mandible contains all of the lower teeth which usually fit together with the upper teeth. Naturally, there are 32 teeth in a human. In about the first ten years of life, deciduous teeth grow and then fall out. There are 20 natural deciduous teeth (Kapit & Elson, 2002). Permanent teeth replace the deciduous teeth and last the rest of a human's lifetime. There is an increasing trend for the third molars (wisdom teeth) to fail to develop or erupt. Teeth are sometimes pulled for physiological or aesthetic reasons.

The crown of a tooth is the part that is exposed outside the gums. There are differently shaped crowns depending on the tooth. Crowns can be made up of cusps, crests, or depressions. A *cusp* is defined as a pointed projection on the chewing surface of a tooth. A *crest* is a projection that models a ridge. A *depression* is an area on the crown of the tooth that is significantly lower compared to other parts of the tooth.

Permanent teeth in the upper and lower jaw can be divided into four types: molars, premolars, canines, and incisors. The anatomy of teeth from the upper and lower jaw differ. For instance, the upper incisors are wider in the frontal plane than the lower incisors. The sides of the lower incisors are also straighter in the lateral direction (Schwartz, 1995). There are eight incisors total, four on the upper jaw and four on the lower.

Fifteen different muscles are associated with the human jaw. Three main muscle pairs are involved in the process of mastication, and also speech—the masseter, temporalis, and pterygoid muscles.

The masseter muscle consists of three layers. All three layers converge onto the zygomatic arch of the maxilla. The superficial layer runs into the lateral surface of the ramus of the mandible. The middle layer runs into the middle of the ramus of the mandible and also into the coronoid process. The deep layer runs into the upper part of the ramus of the mandible and into the coronoid process. The masseter muscle has a branch of the mandibular nerve running through it. This muscle elevates the mandible to move the teeth in mastication. It has a very limited role in side-to-side movement or resting stances of the mandible (Gray, 1995).

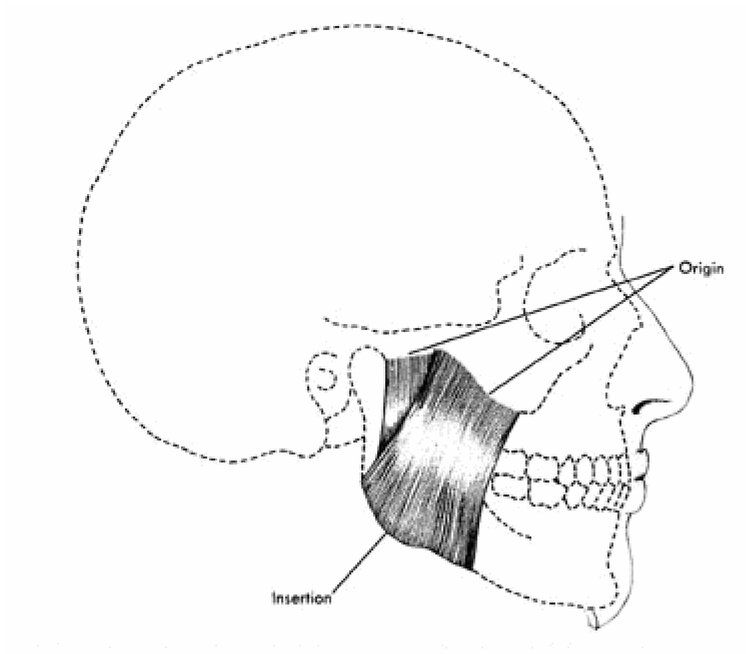


Figure 4: Insertion and Origin of the Masseter Muscle (OUHSC, 2005).

The temporalis muscle runs from the temporal fossa into a tendon. This tendon runs into a gap between the zygomatic arch and the side of the skull. Temporal branches of the anterior branch of the mandibular nerve run through this muscle. The temporalis is involved in raising and lowering the mandible, as well as side-to-side movement of the jaw. The raising and lowering motion occurs with the synchronous upward pull of the anterior fibers of the muscle and backward pull of the posterior muscle fibers (Gray, 1995).

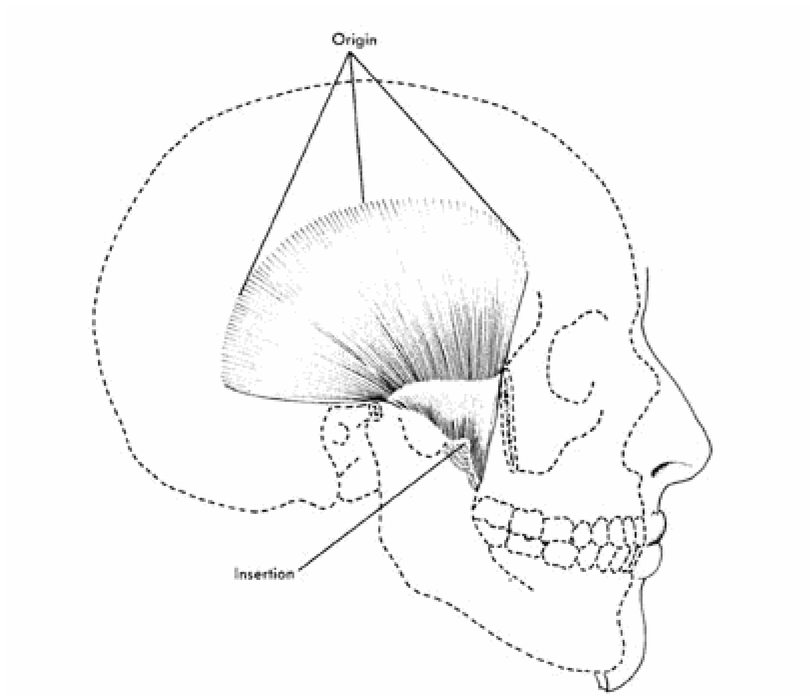


Figure 5: Insertion and Origin of Temporalis Muscle (OUHSC, 2005).

There are two main pterygoid muscles: lateral and medial. The lateral pterygoid has upper and lower parts that both run into the head of the mandible at the temporomandibular joint. The upper part runs from the infratemporal surface; the lower part runs from the lateral surface of the pterygoid plate. The lateral pterygoid helps in both opening and closing the mouth. The medial pterygoid assists in closing the mouth only. The muscle runs from palatine bone and the medial surface of the lateral pterygoid plate into the ramus and angle of the mandible (Gray, 1995). The aforementioned muscles are actively involved in the process of mastication, and therefore it is important to understand their structure and function.

This project requires extensive data analysis and comparison of data acquisition methods. Most of the work will be done in Excel and DaDisp, and there will be no costs needed to carry out the project.

Methods

Analyzing Previously Acquired Data

Data from seven subjects: four male, 3 female, each chewing both banana and cookie samples, were obtained from Dr. Karen Hiiemae. VFG is a method for directly recording jaw motion using x-rays projected on a screen. Subjects sat in a chair and chewed 8 g pieces of food of different consistencies (banana, cookie). While this took place, a lateral projection of the subject's oral cavity area was broadcast onto a 10 inch image intensifier screen. A video timer (VTG-33, For-A, Tokyo) allowed the time to appear in the corner of each image in periods of 0.01 seconds. A video camera recorded the projections at 60 video fields per second. Each subject had a five minute maximum exposure as approved by the Institutional Review Board protocol. All subjects were informed and gave written and oral consent (Hiiemae et al., 1997).

This method, however, has downsides. Because it is only a 2D image, it is only able to record data in those 2 dimensions (Hiiemae and Palmer, 2003). Also, there are reservations about whether this is optimal for determining *tft* contact because it only shows movement in the two dimensions filmed with respect to time. The precision of VFG data is also decreased since its records are made at 60 video fields, or 30 frames per second.

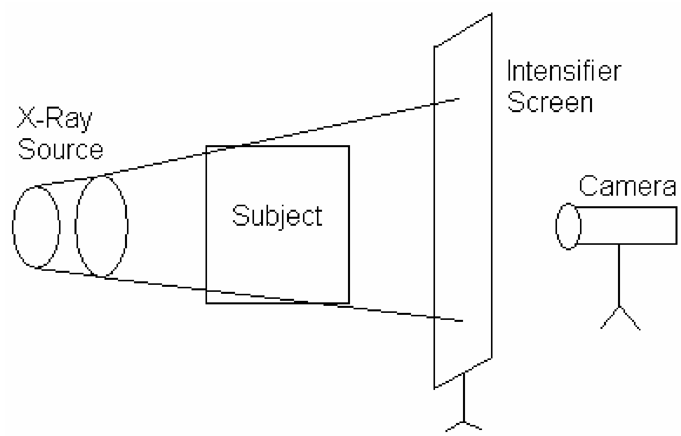


Figure 6: Simple diagram of VFG recording setup. A subject's x-ray is projected onto a screen, which the camera records at 60 video fields per second.

Data Analysis

Mastication data were received in Microsoft Excel format for seven subjects. The methods used to obtain these Excel data are fully described in (Palmer, Hiiemae, & Liu, 1997). The data for each subject were handled separately. One set of data was first obtained, with an x-coordinate column of time in seconds and a y-coordinate column of gape movement in the y-direction, in mm. Each Excel file was converted to a text file so it could be read in DaDisp. A blank lab book was opened in DaDisp and the READTABLE command was used with the text file's location in order to import it into DaDisp.

A DaDisp lab book contains many worksheets which can be connected by functions or commands. The first worksheet used for these research purposes displayed the results of the READTABLE command in the form of a graph and a spreadsheet. In the second worksheet, an XY plot was made from the first spreadsheet. When DaDisp imports data from external sources such as a .txt file, it makes its own x-axis going from 0 to 1000. Having another plot of the same graph allows the original values of the x-axis to be displayed (See Figure 7).

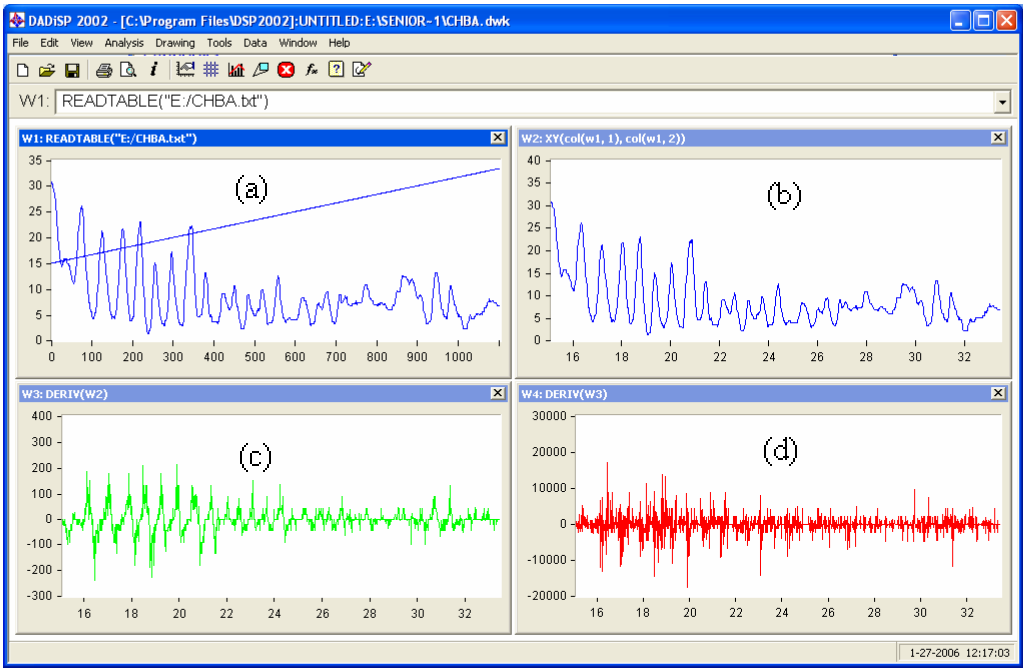
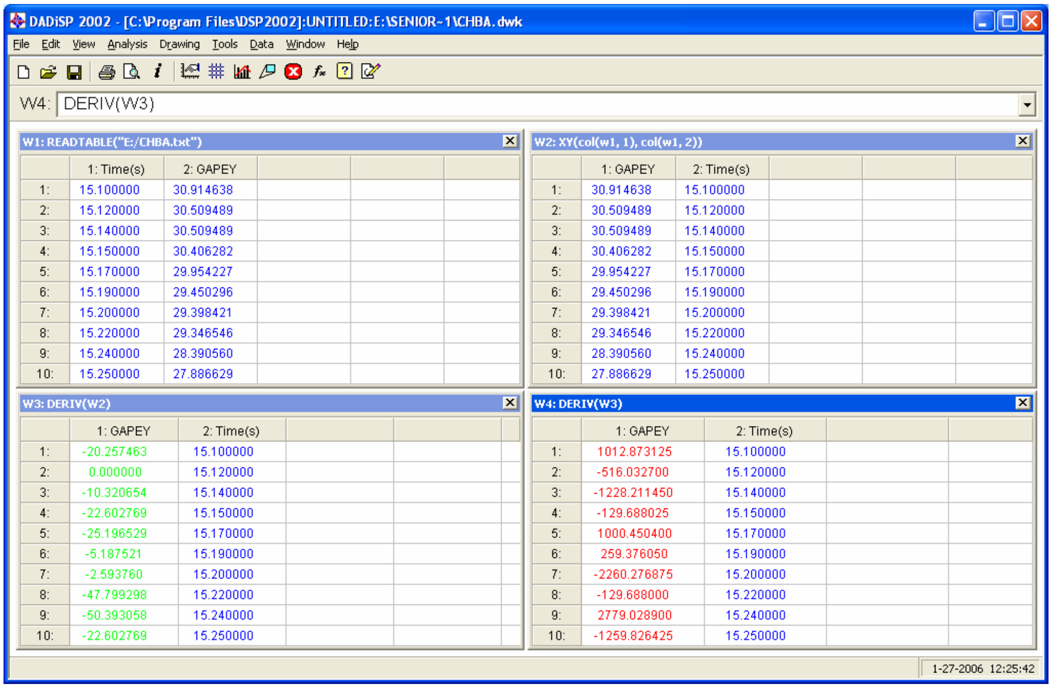


Figure 7: DaDisp screen, showing four worksheets and their graphical displays. Original imported data is shown in (a). The converted x-axis plot (sec) is shown in (b); the velocity is shown in (c), and the acceleration is shown in (d).

In the third worksheet, the DERIV function was used to take the derivative of the 2nd worksheet, providing the velocity of the lower teeth. In the fourth worksheet, the DERIV function was used to take the derivative of the 3rd worksheet, giving the acceleration of the teeth at a given time.

Once these graphs were obtained they were switched into spreadsheet mode for each worksheet (See Figure 8). The y-coordinate column in worksheet 3 (the first derivative and velocity of the teeth) was searched for periods of long strings of zeros that would indicate a maximum or minimum in the original graph. Once these were found, the corresponding times were recorded.



W1: READTABLE("E:/CHBA.txt")

	1: Time(s)	2: GAPEY
1:	15.100000	30.914638
2:	15.120000	30.509489
3:	15.140000	30.509489
4:	15.150000	30.406282
5:	15.170000	29.954227
6:	15.190000	29.450296
7:	15.200000	29.398421
8:	15.220000	29.346546
9:	15.240000	28.390560
10:	15.250000	27.886629

W2: XY(col(w1, 1), col(w1, 2))

	1: GAPEY	2: Time(s)
1:	30.914638	15.100000
2:	30.509489	15.120000
3:	30.509489	15.140000
4:	30.406282	15.150000
5:	29.954227	15.170000
6:	29.450296	15.190000
7:	29.398421	15.200000
8:	29.346546	15.220000
9:	28.390560	15.240000
10:	27.886629	15.250000

W3: DERIV(W2)

	1: GAPEY	2: Time(s)
1:	-20.257463	15.100000
2:	0.000000	15.120000
3:	-10.320654	15.140000
4:	-22.602769	15.150000
5:	-25.196529	15.170000
6:	-5.187521	15.190000
7:	-2.593760	15.200000
8:	-47.799298	15.220000
9:	-50.393058	15.240000
10:	-22.602769	15.250000

W4: DERIV(W3)

	1: GAPEY	2: Time(s)
1:	1012.873125	15.100000
2:	-516.032700	15.120000
3:	-1228.211450	15.140000
4:	-129.688025	15.150000
5:	1000.450400	15.170000
6:	259.376050	15.190000
7:	-2260.276875	15.200000
8:	-129.688000	15.220000
9:	2779.028900	15.240000
10:	-1259.826425	15.250000

Figure 8: Spreadsheet mode for the four worksheets.

The tracing mechanism on DaDisp allowed specific points to be recorded. Each graph could be traced to determine the exact times and amplitudes of specific points on the graph. This tracing method was used extensively to determine the times in the results section.

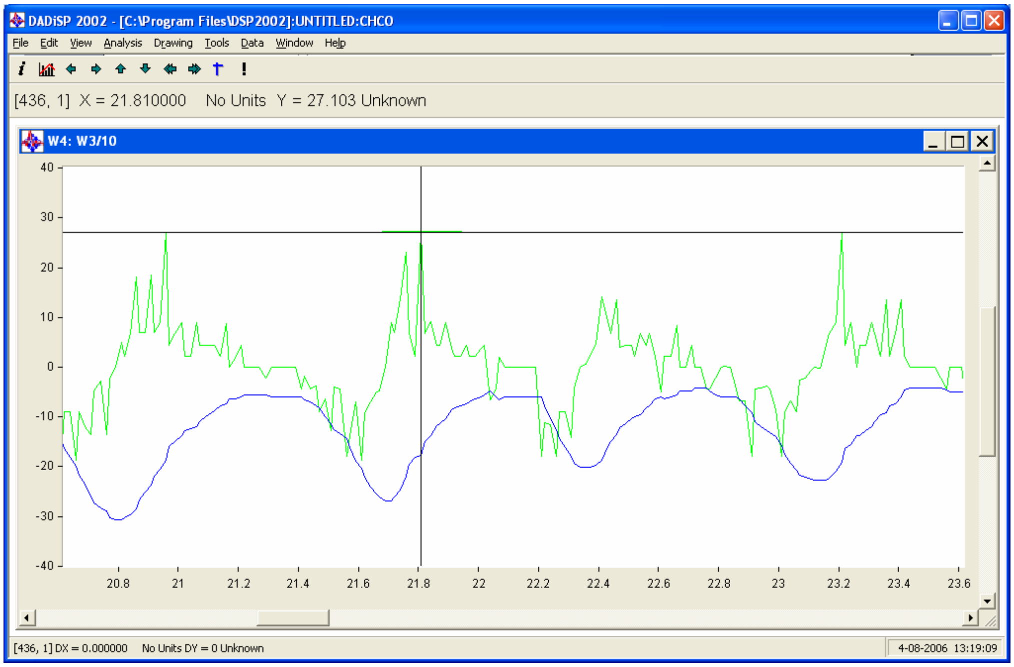


Figure 9: Tracing mechanism on DaDisp, indicating time of maximum velocity at 21.8 seconds in 8th chewing cycle of male chewing cookie.

First, times and amplitudes of maximum and minimum velocities were recorded. Next, times and amplitudes of maximum and minimum accelerations were recorded.

Acceleration data were plotted against motion data to see any changes that might indicate *tft* contact. However, acceleration data were too noisy (see Figure 7d) to see any type of relationship; as a result, only velocity data were further explored.

Next, the jaw-closing time, or crunch time, was recorded for each subject. This is defined as the time of maximum gape (the lowest point on the graph) to the time of occlusion (highest point on the graph). If the graph flat lined at any point the greatest time was taken at maximum gape and the least point was taken at minimum gape. Results can be seen in Table 2 of the Results section.

The crunch time served as the base value for comparison with several other times in the jaw-closing process. These four other times are labeled A, B, C, and D and are described in Table 1 and Figure 9.

Description of Researched Times

Time	Description
A	Time of maximum velocity
B	Start time of greatest velocity increase after time of maximum velocity
C	Start time of greatest velocity decrease after time of maximum velocity
D	Time of zero velocity

Table 1: Description of four times that could possibly indicate *tft* contact.

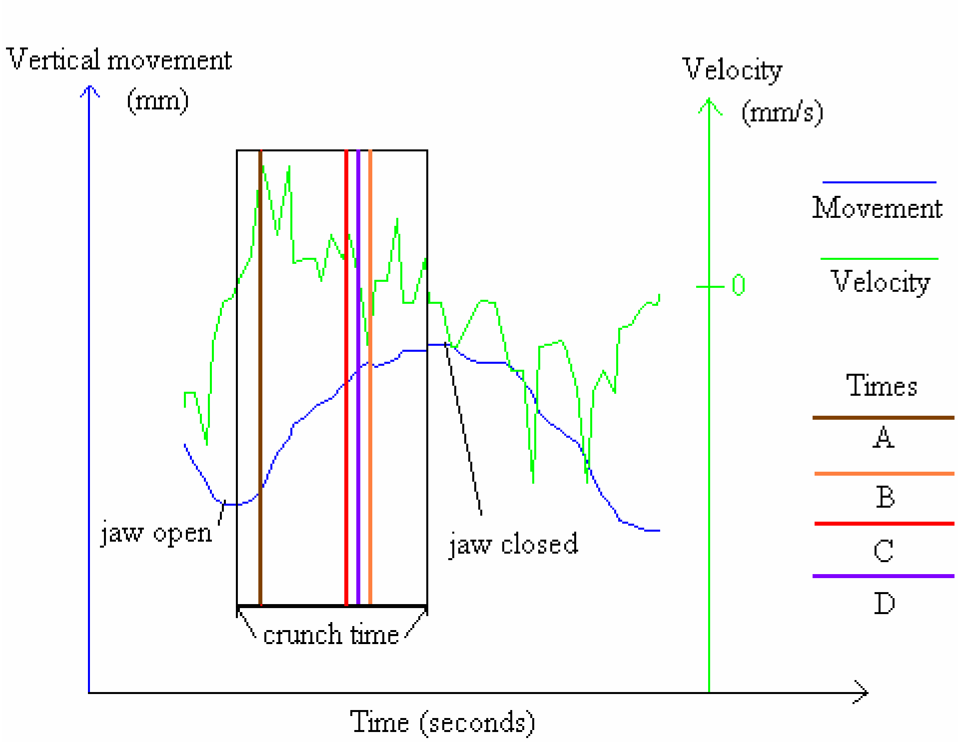


Figure 10: Graph showing the relative times of maximum velocity (A), greatest velocity increase (B)/decrease (C) after max velocity, and zero velocity (D).

These four changes in the velocity data were examined to determine a possible time of *tft* contact. Time A is the time of maximum velocity. If there were two times that showed an equal maximum velocity the later time was recorded. The second point, Time B, was the start time of the greatest velocity increase per unit time. It should be understood that this time was located after the maximum velocity peak and drop and therefore did not include them.

The start time of the greatest decrease in velocity per unit time during jaw closing was also recorded. This was noted as Time C. Like Time B, this time was located after the maximum velocity peak and drop and therefore did not include them. Because the velocity often fell below zero, Time B and Time C included velocity values that were negative as well as positive.

The point where velocity reached zero in each cycle was also recorded for each subject. This was noted Time D.

The above data of proposed contact times were then compared with the videofluorography tapes. Upon viewing the tapes, a time range was recorded for each cycle when the teeth appeared to be in contact. This time range was then compared with the four proposed times of *tft* contact. Results are shown in Table 3.

Results

The analysis of jaw-movement displacement and velocity data for the seven subjects showed four distinct patterns in each cycle that could indicate *tft* contact. The seven subjects each chewed both 8 g pieces of banana and cookie. A table describing each subject's gender, average crunch time, and number of chewing cycles to finish the food is displayed in Table 2:

	Cookie			Banana		
Subject	Average crunch time (s)	Standard Deviation	# of cycles	Average crunch time (s)	Standard Deviation	# of cycles
F1	0.374	0.098	22	0.324	0.109	5
F2	0.253	0.045	23	0.251	0.050	7
F3	0.322	0.072	22	0.308	0.071	5
M1	0.204	0.032	34	0.206	0.057	8
M2	0.322	0.108	30	0.328	0.074	8
M3	0.345	0.083	15	0.340	0.058	6
M4	0.235	0.045	18	0.257	0.030	6

Table 2: Average crunch times for seven subjects chewing banana and cookie. Also noted is the number of chewing cycles used for each subject to consume the food.

A student t-test (α=0.05) was performed to determine statistical differences between average crunch time and number of cycles in the cookie and banana data. The average crunch time t-test showed no statistical difference between the cookie and banana data, with the P value (0.257) greater than the α value of 0.05. There was a statistical difference in the number cycles for chewing the cookie and banana cycles ($P<\alpha$. $0.0001<0.05$). Results can be seen in Tables 3 and 4. The t-test was used assuming normally distributed populations and dependent sample sets.

Average Crunch Time	*Cookie*	*Banana*
Mean	0.293	0.288
Variance	0.003	0.003
Observations	7	7
Pearson Correlation	0.947	
Hypothesized Mean Difference	0	
Degrees of Freedom	6	
t Stat	0.692	
P(T<=t) one-tail	0.257	
t Critical one-tail	1.943	
P(T<=t) two-tail	0.515	
t Critical two-tail	2.447	

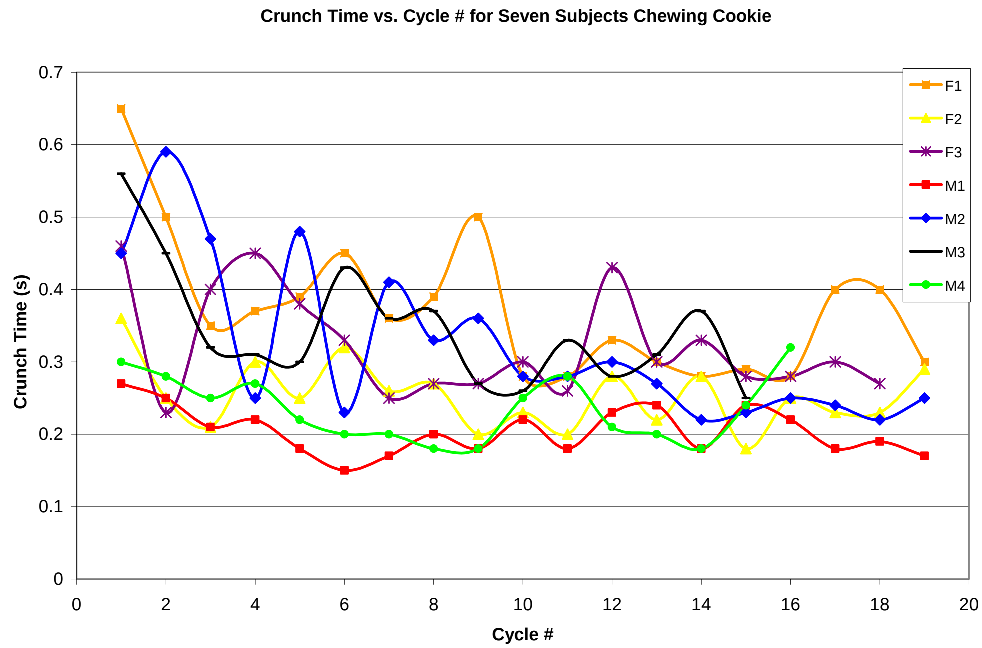
Table 3: Statistical Analysis to test for differences in the average crunch time in cookie and banana samples. The P value (0.257) is greater than the α value of 0.05, meaning there is no statistical difference between average crunch times in cookie and banana samples.

Number of Cycles	*Cookie*	*Banana*
Mean	23.428	6.429
Variance	43.286	1.619
Observations	7	7
Pearson Correlation	0.731	
Hypothesized Mean Difference	0	
Degrees of Freedom	6	
t Stat	7.869	
P(T<=t) one-tail	0.0001	
t Critical one-tail	1.943	
P(T<=t) two-tail	0.0002	
t Critical two-tail	2.447	

Table 4: Statistical Analysis to test for differences in the number of chewing cycles in cookie and banana samples. The P value (0.00011) is less than the α value of 0.05, meaning there is a statistical difference between the number of chewing cycles for cookie and banana samples.

Due to the limited number of cycles used to chew the banana sample, insufficient data were obtained, and hence the data from the cookie sample will be mainly discussed.

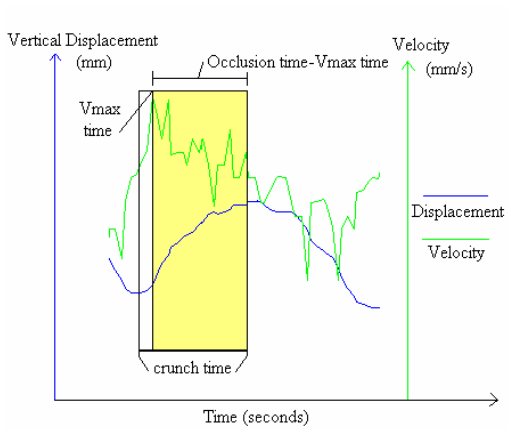
The crunch time for each subject with respect to chew cycle number can be seen in Graph 1:



Graph 1: Crunch time (time from maximum gape to minimum gape) with respect to chew cycle # for seven subjects chewing cookie. The oscillations are a sign of constant variation, and low R^2 values (0.07-0.56) show no correlation. During the second cycle most subjects have a lower crunch time than the first cycle, with the exception of M2.

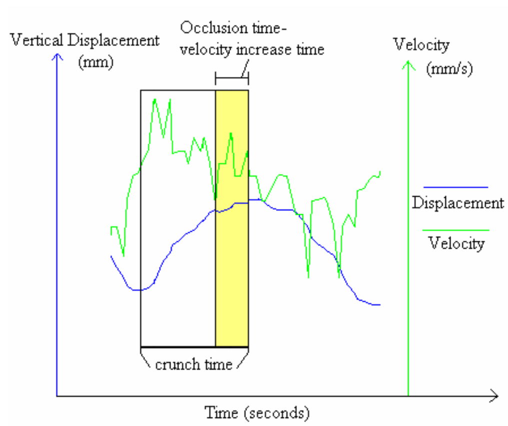
Graph 1 shows the total crunch time (Time between maximum and minimum gape for jaw-closing). Due to the large oscillations in time as cycle number increases, there is no correlation between crunch time and chew cycle number. However, in most subjects there appears to be somewhat of a decrease in crunch time with increasing chew cycle number.

Each time (A, B, C, and D) was compared to the crunch time for each cycle in every subject. This was done by creating ratios of each time over the crunch time. There are several ratios and differences that were taken, however none of them showed a substantial consistency, even within each subject. These ratios can be seen in Figure 11.



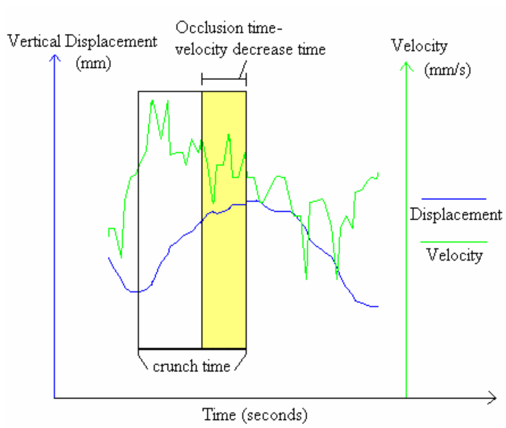
(a)

$$R_A = \frac{time_{occlusion} - time_{V_{max}}}{Crunchtime}$$



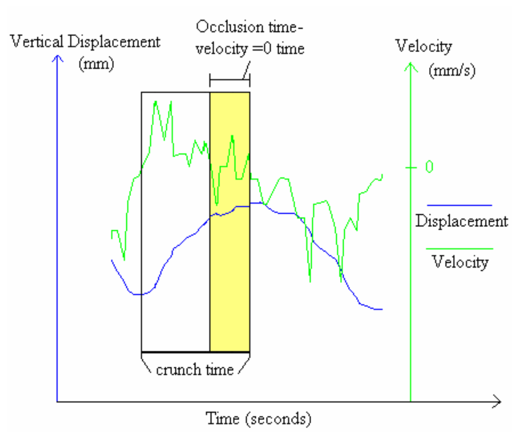
(b)

$$R_B = \frac{time_{occlusion} - time_{V_{increase}}}{Crunchtime}$$



(c)

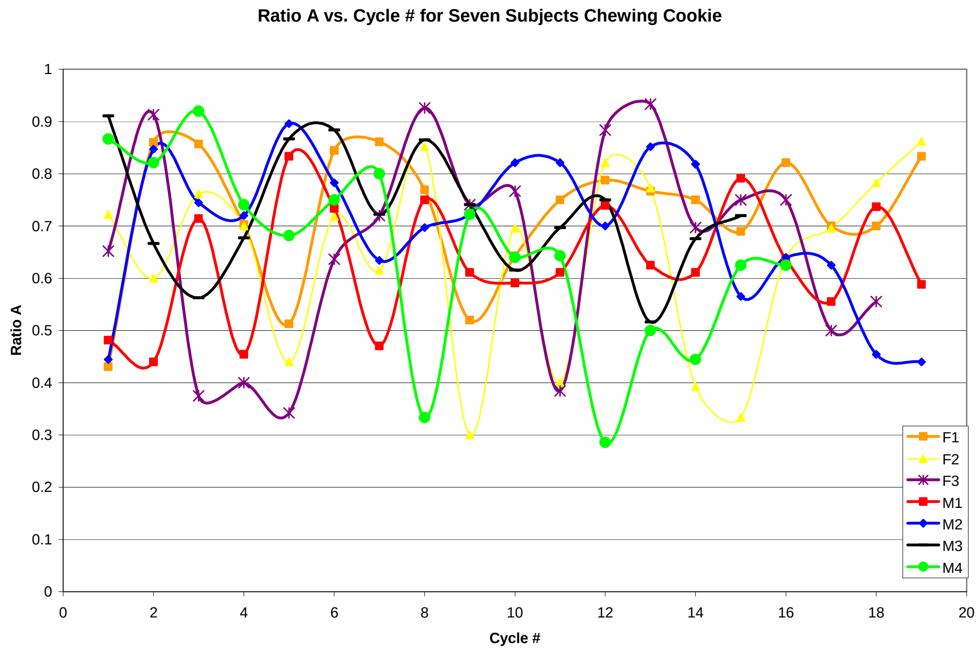
$$R_C = \frac{time_{occlusion} - time_{V_{decrease}}}{Crunchtime}$$



(d)

$$R_D = \frac{time_{occlusion} - time_{V=0}}{Crunchtime}$$

Figure 11: Visualization of four ratios for one cycle. All ratios represent the shaded yellow area over the total crunch time. The cycle shown is the ninth cycle in a male chewing cookie. It is important to note that Time A usually occurred before mid-gape, while Time D occurred either slightly before or at minimum gape.



Graph 2: Cycle # vs. Ratio A. Most ratios observed are over 0.5, however, there appears to be no other pattern.

All ratios were plotted vs. chew cycle number. No trends were found for any of the four ratios. Ratio A is shown in Graph 2.

Each observed time range of *tft* contact from the VFG tapes was then compared to Times A, B, C, and D. Eighty-three percent of the Time C data and 73% of the Time B data had the predicted *tft* contact time within the observed time range of *tft* contact from the videofluorography tapes. These times show better indication of *tft* contact than Time A or Time D, which had less than half of the predicted times within the observed time range.

Time	Percent
A	31%
B	73%
C	83%
D	38%

Table 5: Percent of data that had predicted time within the observed time range from videofluorography tapes.

Discussion

Many properties of mastication have been studied with respect to time and chew cycle number within sequence and as between foods of different consistency. No matter the consistency of the food chewed (hard or soft), many of properties of jaw movement appear to have no trend with respect to time.

Time A showed the time of maximum velocity in each chewing cycle. Most R_A values were over 0.5, meaning that maximum velocity usually occurs during the first half of the crunch time. Since the VFG tapes indicate the teeth do not contact until the second half of the crunch time, Time A is not an indicator of *tft* contact.

Time D showed the time in the jaw-closing process where the velocity equaled zero. Thirty-eight percent of these recorded times were also observed in the VFG video time range for occlusion. Time D was inconsistent with respect to chew cycle number in sequence; sometimes it appeared as the time of minimum gape and others it appeared randomly in the jaw-closing process. This makes Time D another poor indicator of *tft* contact.

Time B showed the start time of the greatest increase in velocity per unit time and Time C showed the start time of the greatest decrease in velocity per unit time during jaw-closing. Seventy-three percent of the Time B data and 83% of the Time C data had the predicted *tft* contact time within the observed time range of *tft* contact from the videofluorography tapes. While these times may indicate *tft* contact, there is no way to predict their occurrence. These times both have poor relationships to the time of maximum occlusion as determined from the DaDisp velocity and displacement graphs. Because of this inconsistency, no equation can be formulated to predict when this *tft* contact will occur in a chewing cycle.

Testing Considerations

There are several factors that may lead the velocity and acceleration data to be inconsistent. The sampling rate (60 video fields/second) is high enough to observe the overall motion of the jaw with respect to time. However, when looking for specific smaller points in time such as *tft* contact, a higher sampling rate is needed. In this experiment, an average crunch time of 0.3 seconds would consist of about 18 data points at a 60 video fields/second sampling rate. From the VFG tapes the time of *tft* contact was known to have taken place in a range of 0.07-0.1 seconds, but the 60 video fields/second sampling rate produced only 4-5 data points for this range. More data points are needed to determine changes in velocity and acceleration.

Variation in individual subjects eating habits may also lead to variable data. The number of chews before each swallow varies from person to person as well as the rate of chewing. Some people naturally chew their food fast and others slowly. Also, there may have been certain occurrences during testing that would have affected the data. It is possible that food could have been moved to the side or back of the mouth and affected the time of tooth contact.

When exactly this could happen in an individual is extremely unpredictable and variable.

Subjects were instructed to chew normally when being tested, however, this may not have held true. All subjects were knowingly in a scientific testing situation and may have acted and chewed differently than if they were eating an everyday meal.

Providing equal samples of food for testing is a difficult procedure. Hard foods (such as the cookie) are often crumbly and soft foods such as the banana can be slippery or sticky. These food properties can cause the sample to be less or more than ideal weight when being cut. However, the use of a chemical/pharmaceutical balance allowed the food samples to be cut with attention to precision.

Another factor that should be taken into consideration is the bite structure, or occlusion of each subject. There are varying degrees of overbites and under bites, which may affect how the subject chews. All of the subjects had incisor and molar Class I occlusion, but slight variations in overbites and under bites can affect the data.

Future Research

The most obvious necessity for future research on this topic is to collect the data with a higher sampling rate. Since we are interested in finding a time in the range of 0.07-0.1 seconds, at least double the amount of data points is needed, setting the sampling rate at 120 video fields/second.

This sampling rate would allow more accurate calculations of velocity and acceleration.

However, the radioactive emissions from the VFG machine were measured at 0.12 rems per exposure of 5 minutes lifetime as compared with the naturally occurring 0.3 rems that the average person is exposed to per year. Radioactive technicians are allowed a 5 rems maximum exposure per year. Increasing the sampling rate of recording requires an increase in the radioactive exposure a subject undergoes. Until technology develops radiographic equipment that allows a higher sampling rate that uses lower radiation than is currently possible, the sampling rate will not be able to be increased for human subjects.

References

Gray, H. (1995). *Gray's anatomy*. New York: Barnes & Noble Books.

Hori, Ono, & Nokubi. (2006). *Coordination of Tongue Pressure and Jaw Movement in Mastication*. Journal of Dental Res. 85(2):187-191.

Kapit & Elson, (2002). *The anatomy coloring book.* Boston: Benjamin Cummings

Hiiemae et al., (1996). *Natural bites, food consistency and feeding behavior in man*. Archives in Oral Biology. 41(2):175-189.

Hiiemae, K. & Palmer, J. (1999). *Food transport and bolus formation during complete feeding sequences on foods of different initial consistency*. Dysphagia. 14:31-42

Hiiemae, K. & Palmer, J. (2003). *Tongue movements in feeding and speech.* Clinical Reviews in Oral Biology and Medicine. 14(6): 420.

Hiiemae, K. Hayenga, S. & Reese, A. (1994). *Patterns of Tongue and Jaw Movement in cineflorographic study of feeding in the macaque*. Archives of Oral Biology. 40(3):229-246.

Palmer, J., Hiiemae, K., & Liu, J. (1997). *Tongue-jaw linkages in human feeding: a preliminary study*. Archives of Oral Biology. 42: 429-441.

Schwartz, J. (1995). *Skeleton Keys*. New York: Oxford University Press

University of Oklahoma Health Sciences Center. *Head and neck anatomy.* Retrieved March 14, 2005 from Department of Dental Hygiene web site: http://dentistry.ouhsc.edu/intranet-web/Courses/DH3342/muscles_mastic.html

Wang M., Zhang M., & Zhang J. (2004). *Photoelastic Study of the Effects of Occlusal Surface Morphology on Tooth Apical Stress from Vertical Bite Forces.* Journal of Contemporary Dental Practice. (5)1:74-93.