# Anterior Open-bite Malocclusion:
# Energetic considerations in the cost of incision.

by

Michael Wayne Sherman

March, 1991

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of
Preventive Dental Science
University of Manitoba

(c) Michael Wayne Sherman

National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-76810-X

Canada

# *ANTERIOR OPEN-BITE MALOCCLUSION: ENERGETIC CONSIDERATIONS IN THE COST OF INCISION*

*BY*

*MICHAEL WAYNE SHERMAN*

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
of the degree of

*MASTER OF SCIENCE*

© 1991

Permission has been granted to the LIBRARY OF THE UNIVERSITY OF MANITOBA to lend or sell copies of this thesis. to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film, and UNIVERSITY MICROFILMS to publish an abstract of this thesis.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

## TABLE OF CONTENTS

## Dedication

To my parents, Annabelle and Irving Sherman for teaching me to appreciate the value of education.

# ABSTRACT

In order to study the energetic efficiency of the masticatory apparatus during the masticatory task of incision, electromyographic (EMG) and videotape recordings were made during masticatory function in four anterior open-bite (AOB) subjects and in four non-anterior open bite (non-AOB) subjects

The subjects were required to incise and chew foods of varying consistencies and dimensions. Using videotape and EMG recordings, time sequencing of specific masticatory activities were defined. Integrated squared (ISq) EMG values, assumed to be linear analogues to muscle energy output, were calculated for the task of incision and the combined tasks of incision and chewing up until but not including first swallow.

ISq EMG values were converted to units of bite force equivalents (BFE) using EMG recordings of isometric biting for calibration. BFE values for each trial were used for statistical analysis.

Variation of incision patterns accounts in part for the variation observed in energy values from the EMG.

For both the masticatory phase of incision alone, and the combined masticatory phases of incision and chewing, no differences between AOB and non-AOB subjects were observed.

However, differences in energy values between food types were observed ($p<0.025$, $p<0.001$) for incision and incision and chewing respectively.

The results show a positive linear relationship between food dimension and energy used for incision ($r=0.828$, $p<0.02$) independent of food consistency. A linear relationship also exists for the combined AOB and non-AOB groups between the energy used for incision and chewing and the food dimension ($r=0.921$, $p<0.005$).

Calculations were done to assess the energy involved in the task of incision as a proportion of the energy involved in the combined tasks incision and chewing (I/IC).

The AOB individuals were found to use a significantly greater proportion of their total masticatory cycle energy than non-AOB individuals to effect incision ($p<0.025$).

A significant interaction effect was also observed between subject sample and food sample ($p<0.025$). The AOB group showed a significant negative linear relationship between I/IC and food dimension ($r=-0.9976$, $p<0.005$). However, the non-AOB group showed no significant relationship between I/IC and food dimension. This indicates that the anterior open bite subjects have greater difficulty incising foods of small dimension, which is expected due to the lack of anterior tooth contact. This difficulty with small dimension foods results in a loss in masticatory efficiency, and is expressed as an increase in cost to the masticatory apparatus.

## Acknowledgements

I would like to express my sincere gratitude to my advisor, Prof. Ken McLachlan. His involvement with this project has taught me several valuable lessons. I am forever grateful for his sense of academic responsibility.

Also, to the other members of my thesis committee, Dr. Felicity Hardwick and Dr. Charles Dowse (external examiner),my sincere thanks for the time and effort taken to review and offer criticism of this thesis project.

My laboratory colleagues, Laura Iwasaki, Jeff Nickel, Peter Trainor, and Julianna Leon, for their unselfish support. Specifically, I appreciate the work of Laura Iwasaki, who established much of the experimental protocol I followed in this project.

Babette Cohen, my classmate and laboratory chum, for the valued friendship. Also, a thanks to the other graduate orthodontic students whose programs have overlapped with mine, for your participation in the learning process.

To my experimental subjects, including Louann (Dermabrasion) Visconti, I recognise that I could not have done this project without you.

Bill Barrett (U. of M., Engineering) for ensuring my access to the videocamera used in this study. Shirley Bond (U. of M., A.C.S.) for her humane help with the animals I used in my previous research efforts.

Elizabeth, my newborn daughter, for the addition of more joy and more celebration at this special time in my life.

Dennis, my son, whose antics have allowed me to maintain a healthy outlook on life while in Winnipeg.

I most deeply and sincerely cherish the love and the selfless support which I have received throughout this graduate program from Melissa, my wife. It is now my turn to offer the same to her.

## List of Figures

Figure: Page:

Chapter 3. Methods and Materials.

Chapter 4. Results.

# List of Tables

Table: Page:

Chapter 3. Methods and Materials.

Chapter 4. Results.

APPENDIX II. Supplementary Study 1

# Introduction

The classification of malocclusion is an integral part of orthodontic diagnosis. The classification infers some common morphological traits among those individuals who are identified as members of a specific group (Moyers, 1973). One such group are individuals with the so-called anterior open bite (AOB) deformity. Morphology as well as etiology may be significant in the location and causation of the AOB problem.

Attempts have been made to identify the specific morphological traits other than anterior dental incompetency, which appear to be pathognomonic features of the AOB deformity (Frost et al., 1980, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Nahoun and Horowitz, 1972, Lowe, 1980). As well, efforts have been made to more clearly understand the basis of, and significance of the etiologic factors in the development of the AOB malocclusion (Shira, 1961, Jarabak, 1983). However, few if any attempts have been made to examine the functional significance of this dental pattern.

The functional efficiency of the masticatory apparatus has been evaluated over the years using comminution tests (Carlsson, 1974). These tests rely on repetitive masticatory cycles, which can be considered of limited use for the elucidation of the functional efficiency during a single event such as incision.

The masticatory apparatus is comprised of the teeth, the jaws, the temporomandibular joint and the muscles (Ramfjord and Ash, 1983). The muscles are guided by nerve activities to perform the functional activity of the system. There is a great deal of knowledge about the muscles of mastication. Electromyography (EMG) has produced interesting and promising studies of masticatory muscle function (Moyers, 1950, Carlsoo, 1952, Pruzansky et at., 1958, Moller, 1966). If an energetic profile of the muscles of mastication can be obtained from EMG, then one can begin to understand the significance of the functional efficiency of the masticatory apparatus during the task of incision.

The objectives of this study were:

1) to propose and utilize a method of deriving a measurement of the energetic profile of the masticatory muscles using EMG.

2) to compare the functional efficiency of the masticatory muscles (i.e. masseter muscle and of the temporalis muscle), as opposed to jaw positional muscles, (i.e lateral pterygoid muscle), between an AOB group and a non-AOB group during various incisive tasks.

3) to determine if there appears to be a penalty incurred upon the masticatory apparatus as a result of an AOB.

# Review of the Literature

"Classification of malocclusion is done for traditional reasons, for ease of reference, for purpose of comparison, and for ease of communication" (Moyers, 1963). Moyers (1963) states that a classification system is a grouping of clinical cases, of similar appearance, for ease of handling, it is not a system of diagnosis, method for determining prognosis or a way of defining treatment.

In orthodontics there are two methods of classification of occlusion used today. The Angle system (Angle, 1899) is still used intact, but the other, the Simon system (Simon, 1924) is only used in parts. These systems are used to describe the dentition in three planes of space; anteroposterior, mediolateral or transverse and vertical.

The Angle system (Angle, 1899) of classifying occlusion or malocclusion is a definition of the teeth in the maxillary and mandibular arches relative to each other in space. It appears to have no bearing on the relationship of the teeth to their supporting skeletal bases, or the relationship of the skeletal bases with one another. Angle (1899) defined "the relative position of the first molars" as the key to occlusion. He (Angle, 1899) further stated that "In normal occlusion the mesio-buccal cusp of the upper first molar is received in the sulcus between the mesial and distal cusp of the lower, the slight overhanging of the upper teeth bringing the buccal cusps of the bicuspids and molars of the lower jaw into the mesio-distal sulci of their antagonists".

In the Angle classification scheme Class I malocclusion exists when the first molars are well related mesiodistally, and other teeth in the arch are poorly related to their antagonist. A malocclusion is defined as Class II when the "lower teeth are found occluding distal to normal"(Angle, 1899). Conversely, the Class III group have " all the lower teeth occluding mesial to normal"( Angle 1899). One assumption in Angle's method of classification is that the position of the upper molar is invariably correct.

The classification scheme used by Simon (1924) does not follow Angle's assumption of the maxillary molar position being the key to occlusion. The anteroposterior (A-P) relationship of the dental arches is defined by their position relative to the orbital plane. When the dentition or part thereof was anteriorly placed relative to the orbital plane it is said to be in protraction. Conversely, when the dentition is posterior to the orbital plane it is said to be in retraction (Simon, 1924). The fact that Simon found the maxillary cuspid region to fall on the orbital plane in a high percentage of normal occlusions led him to define this relationship as the Law of Cuspid.

Contrary to the opinion of Moyers (1963), the classification scheme proposed by Angle (1899) does address malpositions of the teeth in the transverse and vertical dimension. Angle (1899) states the individual teeth can occupy one or more of seven distinct malpositions from the harmonious line of occlusion. In the transverse a tooth can either be in buccal or labial occlusion, or in lingual occlusion relative to the line of harmony.

To provide a transverse description, Simon (1924) looks at the position of the dentition relative to the midsagittal plane. When nearer to the midsagittal plane the teeth are said to be in contraction, and when the arch or a part of it is further from the midsagittal plane they are said to be in distraction.

Simon (1924) uses the Frankfurt plane as his plane of reference for vertical relationships of the dentition. He labels the dentition as being in attraction when nearer than normal to the Frankfurt plane, and in abstraction when further than normal from the Frankfurt plane.

Angle (1899) only labels vertical abnormalities of single teeth. Teeth not sufficiently elevated in their sockets would be in infra-occlusion and those over elevated would be in supra-occlusion. However, Angle (1899) does describe the vertical relationship of the anterior six teeth, or overbite, in his discussion of the normal occlusion. He states that the upper central, lateral and cuspid teeth overlap the lower by about one-third of the length of their crowns.

The schemes for classification of malocclusion which have been proposed by Angle (1899) and by Simon (1924) provide ease of reference, ease of communication between clinicians and, ease of comparison between cases. The category of malocclusion may be an essential part of the final orthodontic diagnosis. Other factors, including the morphological skeletal features, facial appearance, patients age, etc., none of which are necessarily mutually exclusive, also contribute to the final case diagnosis. However, neither the scheme of Angle nor that of Simon communicate the etiology of the malocclusion. The establishment of the correct diagnosis and etiology is very important and may indeed dictate the method and choice of treatment.

Apertognathia, or open bite is used to describe the failure of the teeth to touch when the jaw is closed. According to Kwon et al. (1984) this deformity produces social and psychological distress in patients as well as functional problems. AOB deformities have many distinct morphological features associated with the anterior dental incompetency. As well, the AOB is manifested as a result of several etiologic factors.

Several studies have compared the morphological features of AOB individuals with non-AOB individuals (Cangialosi, 1984, Frost et al., 1980, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Nahoum, 1971, Nahoum and Horowitz, 1972, Enunlu, 1974 and Lowe, 1980). The anterior open bite malocclusion may be associated with any form of anteroposterior skeletal and dental relationship. However, cephalometrically, many distinguishing morphological features have been reported.

Beginning superiorly with the cranial base, Subtelny and Sakuda (1964) found a normal anterior cranial base, but a short posterior cranial base in open bite individuals.

Muller (1963) found open bite occurring in individuals with deep positioning of the nasal floor relative to cranial base, leading to the hypothesis of less space for the tongue which in turn becomes displaced between the dentition. Contrary to this, Sassouni and Nanda (1964), Nahoum (1975) and Trouten et al. (1983) reported an upward cant on the anterior part of the palate related to short upper face height, further contributing to the height of the lower face in open bite patients.

Others (Subtelny and Sakuda, 1964, Enunlu, 1974, Frost et al., 1980, and Lowe, 1980) found no significant difference between AOB and non-AOB groups with regard to the angle of palatal plane relative to cranial base (sella-nasion plane to palatal plane). This may indicate that the deformity arises inferior to palatal plane. Thus, there is no clear relationship between the orientation of the palate to the orientation of anterior cranial base in AOB individuals.

An increase in the angle between sella-nasion plane and the occlusal plane has been reported by many investigators

(Frost et al., 1980, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Enunlu, 1974, Lowe, 1980, Schendel et al., 1976). The above studies used one occlusal plane midway between the incisors to the mesiobuccal cusp of the first molars. Others (Nahoum et al., 1972, and Enunlu, 1974) constructed both maxillary and mandibular occlusal planes, and found no significant difference in maxillary occlusal plane angles between AOB and non-AOB individuals. They did report a significantly greater mandibular occlusal plane angle in AOB individuals. Thus, one may conclude that the AOB deformity arises below the maxillary dentition.

A common finding among investigators is that mandibular plane angle is consistently larger in the skeletal open bite patients than in non-AOB individuals (Frost et al., 1980, Swinehart, 1942, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Nahoum, 1971, Nahoum et al., 1972, Enunlu, 1974, Schendel et al., 1976, Trouten et al., 1983, Lowe, 1980, Hapak, 1964, Schudy, 1964, Bjork, 1969, Sassouni, 1969, Issacson et al., 1971, Kim, 1974, Arvystas, 1977, Ellis and McNamara, 1984). Sassouni and Nanda (1964) found that the mandibular condyle in AOB patients was located in a superior position relative to non-AOB patients. This feature may decrease effective ramus height, thus producing a larger mandibular plane angle. Many researchers (Richardson, 1969, Subtelny and Sakuda, 1964 and Schendel et al., 1976) report mandibular retrusion relative to cranial base in open bite cases. Therefore, one may conclude that the anatomic relationship of mandible and cranial base may be a distinguishing feature in those with AOB deformities.

The gonial angle in skeletal open bite cases is significantly larger then non-AOB cases (Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Nahoum et al., 1972, Enunlu, 1974, Richardson, 1969, Schendel et al., 1976 and Trouten et al., 1983). This feature may explain the associated large mandibular plane angles in AOB cases.

Investigators also report a shorter than normal posterior facial height in patients with AOB malocclusion (Frost et al., 1980, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Nahoum et al., 1972, Enunlu, 1974). Some report that short mandibular ramus (Hellman, 1931, Swinehart 1942) and mandibular corpus (Hellman, 1931) characterise AOB deformities. A short ascending ramus along with a normal gonial angle would still tend to produce a larger than normal mandibular plane angle. It appears three factors may be additive in the production of the steep mandibular plane angle in the AOB population: short posterior face height, obtuse gonial angle, and a downward and backward position of the mandibular ramus (Ellis and McNamara, 1984).

The mandibular dental contribution to the AOB deformity is poorly defined. Hapak (1964) reported high values for mandibular incisor alveolar height in AOB patients.

Overdevelopment of the posterior maxillary dentoalveolus has been indicated as a factor in AOB cases (Frost et al., 1980, Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Bjork, 1969, Issacson et al., 1971). Conversely. Swinehart (1942) found infraocclusion of the maxillary teeth in open bite cases. However, Nahoum et al. (1972) found no difference between AOB and non-AOB subjects with regard to maxillary posterior dentoalveolar height. Thus, the contribution of posterior maxillary development in AOB deformities is not known reliably.

Increased total anterior face height has been considered a factor in open bite malocclusion (Hapak, 1964, Subtelny and Sakuda, 1964, Richardson, 1969, Nahoum, 1975, and Loufty, 1973). Some investigators report increased lower anterior face height (anterior nasal spine to menton) as the major contributor to increased overall face height (Frost et al., 1980, Sassouni and Nanda, 1964, Nahoum, 1971, Nahoum et al., 1972, Hapak, 1964, Schudy, 1964, Sassouni, 1969, Arvystas, 1977, Richardson, 1969, Moyers, 1963). Many report that upper anterior face height appears to remain within normal limits (Sassouni and Nanda, 1964, Subtelny and Sakuda, 1964, Hapak, 1964) or may be shorter in AOB patients (Nahoum, 1971, Enunlu, 1974, Lowe, 1980). From the literature, it appears that an increased anterior vertical face height is likely a distinguishing morphological feature of the AOB deformity.

There are a variety of etiologic classification schemes for the anterior open bite malocclusions. Jarabak (1983) classifies etiology based on the two schools of thought with regard to treatment. He (Jarabak, 1983) attributes etiology in the first group to local or habitual factors which can be treated by removing the functional etiology with orthodontic or orthopaedic appliances, or by tonic training of the perioral musculature along with tongue muscle retraining. The second group have skeletal etiology and should be corrected surgically.

To distinguish these treatment based groups, Cangialosi (1984) found that open bites of habitual etiology have anterior teeth that are undererupted because of the presence of some object (thumb, tongue, pencil, etc.). However, skeletal open bites demonstrate normally erupted or overerupted anterior teeth (Cangialosi, 1984). This report (Cangialosi, 1984) suggests that vertical dental patterns may be used to distinguish the skeletal contribution to the open bite deformity.

The method of classification of AOB etiology by Shira (1961) states that the AOB malformation may be developmental or acquired. Acquired open bite is the most common form and may be produced by intrinsic or extrinsic factors (Shira, 1961).

Extrinsic factors are related to habits which prevent the normal eruption of the teeth. According to many authors (Kwon et al., 1984, Subtelny and Sakuda, 1964 and Jarabak, 1983) these habits include thumb or finger sucking, or the use of pacifiers. Trauma such as a fracture of the mandible or maxilla when inadequately treated may also be considered an acquired extrinsic etiologic agent (Kwon et al., 1984)

Intrinsic factors are those associated with improper action of the tongue, lips and cheeks during mastication, swallowing and speaking. Many or all open bite malocclusions are tongue posture or function related in one form or another (Kwon et al., 1984). However, Jarabak (1983) states the question that still needs to be answered: "Is incorrect tongue function the cause of the open bite, or is it a functional adaptation to the open bite, with the tongue remotely screened in the craniofacial morphology, that is the actual cause of the open bite?"

The influence of oral respiration on craniofacial growth and dental malocclusion has been described in the literature for many years (Jarabak, 1983, Linder-Aronson, 1970, 1975) . Linder-Aronson (1970) investigated patients preoperatively and postoperatively who had adenoidectomy and summarized his conclusions as follows: the characteristics of the chronic mouth breathers were a narrow upper jaw, retroclined upper and lower incisors, normal palatal vault height, and tendencies toward having cross bites and open bites. Thus it seems that mouth breathing may be considered an intrinsic acquired factor in the etiology of AOB in some patients.

Another intrinsic factor may be the underdevelopment of the premaxilla which has been described as a cause for open bite malocclusion (Thoma, 1969). However, the open bite may be idiopathic in origin or secondary to another disease process.

Opinions on the role of congenital factors as an etiology to apertognathia are varied. In 1931, after observing treated and spontaneously resolved open bite malocclusions, Hellman suggested that open bite is primarily due to skeletal growth deficiencies. In support of this concept, Shira and Alling (1970) mention that open bite develops on a genetic or developmental basis. The process may be exaggerated or muted by various systemic pathological and/or environmental factors.

Proffit and Bell (1980) indicated that the vertical growth of the jaws may be genetically determined. To illustrate this point, they cited the incidence of open bite in blacks and caucasians. Incidence of open bite is seven times as high in blacks when compared to caucasians, and deep bite is seven times as high in caucasians when compared to blacks.

Tongue posture has also been postulated as a developmental etiologic agent (Jarabak, 1983, Swinehart, 1942, Straub, 1960, Neff and Kydd, 1966 and Hovell, 1968). In patients with tongue thrusting behavior, the mere presence of the tongue between the teeth is not enough to induce deformity (Neff and Kydd, 1966). The tongue thrust during deglutition is principally dictated by the surrounding anatomy, the tongue is thrust forward in order to effect an oral seal (Subtelny and Subtelny, 1973).

From a cross-sectional sample, Worms et al. (1971) found apparent spontaneous correction of anterior open bites in children from an 8 year old age group to an 11 year old age group. It has been shown that tongue thrust is the most common pattern of swallowing up to age 10 (Schudy, 1964, Ward, 1961). After that age there is a decrease in this form of swallowing, possibly accounting for the spontaneous correction of anterior open bite previously referred to. The above authors (Worms et al., 1971 and Schudy, 1964) therefore conclude that tongue posture is not considered a prime etiologic factor in AOB deformity.

Conversely, Hovell (1968) considers that tongue thrusting may be a faulty pattern of motor activity of the tongue, almost certainly an innate neuromuscular pattern. Perhaps it is the innate inability to change from the tongue thrusting swallow to a non-tongue thrusting swallow which is the predisposing etiologic factor. This inability to change may be the result of inadequate airway volume, resulting in chronic anterior posturing of the tongue.

Thus, innate features such as excessive tongue volume may contribute to the AOB deformity (Roehm, 1981). An adaptation to a large tongue may be that the jaw rotates open and the tongue protracts in order to accommodate the airway, leading to an anterior open bite (Lowe et al., 1977). In the past because of the high correlations between anterior open bite and tongue thrusting, many investigators have considered tongue thrust to be the etiologic factor in the causation and perpetuation of this malocclusion. The AOB may be a functional adaptation as a result of a disproportion in size between tongue and oropharynx.

Kydd et al. (1963) found horizontal tongue pressure against the lower incisors in anterior open bites to be twice that of controls. However, Proffit et al. (1969) found that the majority of patients with open bite and tongue thrust habits exerted little or no tongue pressure on the lingual surface of lower incisors. Thus the effect of tongue pressure is somewhat inconclusive.

Mastication is often described as occurring in three stages: (1) incision, (2), crushing and diminishing of the size of large particles, and (3) milling or trituration of the food preparatory to swallowing (Ramfjord and Ash, 1983). The latter two stages are difficult if not impossible to discriminate from one another (Ramfjord and Ash, 1983). Incision, however, is a discrete step in mastication.

Natural incision was studied by Jankelson et al. (1953). These investigators looked at the functional differences in incision for foods of different consistencies. With highly resistant foods, incision often occurred with incisors in an end to end position (Jankelson et al., 1953). With moderately resistant foods, the mandible was protruded in order to grasp the food, but retrusion of the mandible toward centric occurred during incision (Jankelson et al., 1953). This retrusion toward centric was often interrupted before the mandible had returned completely to the centric position (Jankelson et al., 1953). With soft foods the mandible was again protruded in order to grasp the foods, then the food was sheared with the mandible moving retrusively toward centric position without interruption (Jankelson et al., 1953).

Jankelson et al. (1953) also report that it was plain that incision of food is seldom performed by the teeth alone. The action of the teeth was aided by the head and shoulders pulling backward, and the hand and arm pulled , twisted, and tore the food forward and downward in the opposite direction, until it broke the area thinned by the teeth. Contact of teeth seldom occurs during the act of incision because the food tears off at the thinned portion before it is cut entirely through. In summary they (Jankelson et al., 1953) reported that incision, then, was not a simple act of teeth cutting through food until it was severed.

AOB individuals are unable to appose their incisors when attempting incisal function. The literature is devoid of references to scientific research about the act of incision in people with AOB deformities. Thus, a suitable method of evaluating the efficiency of the masticatory apparatus of AOB during incision has not been described. However, masticatory efficiency has been evaluated by many researchers in the past (Christiansen, 1924, Dahlberg, 1942, Manly and Braley, 1950, Kawamura and Nobuhara, 1957, Loos, 1963, Yurkstas, 1965, Helkimo et al., 1977, Nagasawa and Tsuru, 1973, Astrand, 1974, Tzakis et al., 1989).

Masticatory efficiency (chewing efficiency) is often defined as the capacity to reduce food during mastication (Tzakis et al., 1989). As it differs from individual to individual, it is usually measured with a comminution test (Carlsson, 1984). In this portion of the review of the literature the terms masticatory efficiency and chewing efficiency will share a common definition (above), and will be used according to the choice of the authors of the cited literature.

Several variables have been used to estimate chewing efficiency. For example, the time required to grind a certain amount of food to a degree that a subject feels it is suitable to swallow and the number of chewing strokes required to get a corresponding grinding (Kawamura and Nabuhara, 1957, Nagasawa and Tsuru, 1973). Another variable is the degree of grinding of a piece of food within a given number of chewing strokes (Manly and Braley, 1950, Yurkstas, 1965, Nagasawa and Tsuru, 1973), or during a given time (Loos, 1963, Helkimo et al., 1977). The degree of trituration of the food has mostly been determined by expectoration of the chewed bolus and fractionating it through a series of sieves (Christiansen, 1924, Dahlberg, 1942, Helkimo et al., 1977). This technique has remained the method of choice and, with minor variation, is still used (Tzakis et al., 1989).

Bates et al. (1976) believe that there are two ways to measure the ability of the masticatory apparatus: (1) The masticatory performance which involves measuring the particle size distribution of food when chewed for a given number of strokes; (2) The masticatory efficiency which involves counting the number of masticatory strokes required to reduce food to a certain particle size.

Thus, these previously described masticatory efficiency studies obtain both a measure of the masticatory input; i.e. the number of chewing strokes or chewing time and, a measure of the masticatory output; i.e. the particulate size in the masticated bolus. They use these values to calculate the efficiency of the system. There are several factors which are thought to be capable of influencing chewing efficiency such as the dentition, oral soft tissues, swallowing threshold, chewing habits and dysfunction of the masticatory system (Carlsson, 1974, Bates et al., 1976, Gunne, 1985). The contact surfaces or the number of contact points in occlusion, has, for example, been shown to be much better correlated with chewing efficiency than the number of teeth alone (Dahlberg, 1942, Yurkstas and Manly, 1949). Also, Manly (1951) devised a table from which masticatory efficiency could be determined for any give food platform area and molar imprint length. Clinically, then, the number of occluding pairs of teeth may be regarded as a relatively reliable measure of chewing efficiency defined as the capacity to crush and grind food

(Carlsson, 1974).

The soft tissues, more specifically the tongue, can play a significant role in mastication. The functions of the tongue can include: (a) direct crushing of the food by pressing it against the rugae of the hard palate; (b) pushing food onto the occlusal table; (c) mixing of the bolus with saliva; (d) selection and separation of fragments of the bolus which have been sufficiently chewed to be swallowed, and (e) participation in the after chewing removal of residual fragments of food from around the teeth and alveolar process (Carlsson, 1974). Also the cheeks and lips take part in various phase of chewing (Carlsson, 1974).

The swallowing threshold is considered the degree of trituration or the size of the morsels of the food when an individual feels that the food has been sufficiently chewed to be swallowed (Carlsson, 1974). In cross sectional studies, Dahlberg (1942, 1946) and Yurkstas (1965) reported that persons with impaired chewing efficiency appear to compensate for this by swallowing larger particles and not by chewing the food longer or by increasing the rate of chewing. The above research has not been confirmed by longitudinal studies, and because the range of individual variation is so wide generalizations should be avoided (Carlsson, 1974).

Chewing habits appear to be constant for an individual. Dahlberg (1946) reports that characteristic changes in the dentition, if they occur gradually, do not appear to alter the chewing pattern or number of chews. When forced to chew at specific rates individuals gave the best effect at a "normal" rate of 1 stroke/second (Yurstas, 1965). Thus, a change in habitual rate of chewing will probably impair the effect of chewing (Carlsson, 1974).

Efficiency (Ef) is defined as a ratio of Energy output ($E_o$) to Energy input ($E_i$). Thus, $Ef = E_o / E_i$. Another method to evaluate the efficiency of the masticatory system would be to measure the masticatory muscle input ($E_i$) for a standard masticatory task ($E_o$). Muscle input or energy could be evaluated directly by invasively measuring changes in blood flow and oxygen uptake or by measuring changes in lactate production by the muscles involved in the task (Warren, 1966). However, an indirect measure such as EMG will be a less invasive measurement tool. EMG may prove useful for the study of muscle efficiency during the masticatory task of incision because it has been used extensively to study the muscles of mastication (McCollum, 1943, Moyers, 1949, Carlsoo, 1952, MacDougall and Andrew, 1953, Latif, 1957, Woelfel et al., 1960, Moller, 1966, Ahlgren, 1966, Vitti, 1971, Ahlgren et al., 1973, Lowe et al., 1983).

During incision, Latif (1957) and MacDougall and Andrew (1953) found that all parts of the temporalis muscle were active, with greater activity in the anterior fibres, but in many individuals the posterior fibres were predominant, while in some activity was similar throughout the muscle. Vitti

(1971) reported that anterior and middle fibres of the temporalis muscle were active within individuals with posterior dental support. In the edentulous patient he found all three parts of the temporalis muscle were active (Vitti, 1971).

However, in mandibular protrusion studies some investigators report no activity in the anterior fibres of the temporalis muscle (Latif, 1957, Carlsoo, 1952, Woelfel et al., 1960, Moller, 1966). Moyers (1949) and McCollum (1943) found anterior temporalis fibres active during protraction, contrary to the other findings above. Ahlgren et al. (1985) found that the EMG activity of the temporalis muscle decreases during incisive bite, and that only the anterior fibres showed some activity during a strong biting force. Ahlgren et al.(1985) concludes that during incision the temporalis muscle shifts the burden of supporting the jaw to the muscles that protrude it (i.e. lateral pterygoid muscle), and that the temporalis acts mainly as a stabilizer.

The work of Jankelson, (1953) suggests that there is a retrusive component to incision in moderately soft foods. Also studies of pure maximal protrusion (Latif, 1957, Moller, 1966) with no vertical resistance, may be very different from those involved in incision where vertical force production is required (Ahlgren et al., 1985). Thus differences in findings between studies of protrusion and those of incision may be explained by the above mentioned factors.

In molar occlusion all of the fibres of the temporalis muscles show marked activity levels as this is the primary function of this muscle (Latif, 1957, Ahlgren, 1966, Vitti, 1971, and Vitti and Basmajian, 1975, 1977).

The masseter muscle is very active during forceful centric occlusion clenching (Pruzansky, 1952, Moyers, 1950, Ahlgren, 1966, Vitti and Basmajian, 1975, 1977). In protrusion, the superficial masseter muscle shows some activity (Carlsoo, 1952, Vitti and Basmajian, 1977).

The lateral pterygoid muscles are considered the prime movers of the mandible during protrusive excursions or as an initiator for incisor clench (Lehr and Owens, 1980). Moller (1966) showed that during maximum protrusion of the jaws the lateral pterygoid was more active than the digastric muscles. The activity of the digastric muscle is most prominent at the end of mandibular depression (Ramfjord and Ash, 1983). These muscles are not considered to be involved in molar clenches and show very liitle involvement as a stabilizer during ipsilateral translations (Lehr and Owens, 1980).

The medial pterygoid muscle is predominantly a jaw elevating and lateral postioning muscle (Ramfjord and Ash, 1983). It acts in synchrony with the masseter and temporalis muscles. However, the medial pterygoid muscle contribution to comminution are small compared to the masseter muscle.

One concludes that the medial and lateral pterygoid muscles, and the digastric muscles contribute to the overall masticatory energy profile for the tasks of incision and chewing. However, their contributions are small and in synchrony with the temporalis and msseter muscles.

To have an insight into how a measurement of masticatory muscle energy may be obtained from EMG it is useful to quote an electrical analogue. Energy (E) in a circuit is defined as the integral of the power with respect to time (E = P dt) (Budak, 1978). In basic electric principles the power (P) in the circuit is equal to the voltage multiplied by the current (P = v x i) (Budak, 1978). Basic principles also state that current (i) is equal to the voltage (v) divided by the resistance (R) in a circuit (i.e. i = v / R) (Budak, 1978). Thus to calculate the Power in a circuit in terms of voltage and resistance one finds that $P = v^2 / R$. Since electrical activity of a muscle is a measure of force exerted by that muscle (Ralston, 1961), a method of quantification of the electromyogram to measure the energy input of the masticatory muscles will allow a more complete evaluation of energetic efficiency of the masticatory apparatus.

# Materials and Methods

## A. The Experimental Sample.

The sample population consisted of 8 subjects of both sexes (4 males and 4 females), ranging in age from 17 years 2 months to 33 years 8 months, with a mean age of 24 years 1 month. There were two distinct groups in the sample population: (1) the AOB group and; (2) the non-AOB group. Selection was based on the agreement of the subject to participate in the study, after being fully informed as to the purpose of the study, and signing the necessary consent form (Appendix A). All subjects had complete permanent dentitions, and none had received comprehensive orthodontic treatment prior to the study.

The AOB group was selected from patients of the Graduate Orthodontic Clinic of the University of Manitoba. This sub-population consisted of 2 males and 2 females, ranging in age from 17 years 2 months to 33 years 8 months, with a mean age of 21 years 10 months. All subjects in this group had an anterior open bite ranging from 0.0 mm. to 4.0 mm., with a mean of 1.9 mm open bite (Table 3.1). Subject P.S. with 0.0 mm open bite in the central incisors region, had 2.5 mm open bite in the lateral incisor and cuspid regions.

The non-AOB group were selected from the student

Table 3.1. Static Dental Relationship of Subjects

| Subject | Overbite (mm) | Overjet (mm) | Angle Classification of Malocclusion |
|---|---|---|---|
| M.C. * | 4.0 | 1.5 | Class I |
| G.H. * | 2.0 | 3.0 | Class I |
| R.K. * | 2.5 | 2.5 | Class I |
| E.P. * | 2.0 | 2.75 | Class I |
| non-AOB Mean | 2.63 | 2.44 | ------ |
| L.M. + | -4.0 | 5.0 | Class I (Cl II cuspid) |
| P.S. + | 0.0˜ | 0.0 | Class III |
| T.S. + | -1.5 | 3.0 | Class I |
| M.W. + | -2.0 | 6.0 | Class II |
| AOB Mean | -1.88 | 3.5 | ------ |

* non-AOB
\+ AOB
˜Subject has -2.5 mm overbite in lateral incisor and cuspid region.

population of the Faculty of Dentistry at the University of Manitoba. This sub-population consisted of 2 males and 2 females ranging in age from 23 years 11 months to 31 years 0 months, with a mean age of 26 years 6 months. All subjects in this group were Angle Class I malocclusion, with an anterior overbite ranging from 2.0 mm. to 4.0 mm. with a mean of 2.63 mm. (Table 3.1).

### B. The Electromyography Apparatus.

The electrical activity from the right and left masseter and right and left anterior temporalis muscles were monitored using Grass silver cup 7 mm. diameter surface electrodes (Figure 3.1). Four electrode pairs and four amplifiers were used. Each electrode pair was connected to a very high input impedance and strong common mode rejection preamplifier having a voltage gain of 100 (Figure 3.2). The output from the preamplifier was input to the second stage amplifier using an optical coupler.

The second stage amplifier had adjustable, first order, low and high pass filters (Figure 3.2). There was an adjustable gain control which provided up to 100 times gain. Thus, the maximum system voltage gain is 10,000. The second stage amplifier is limited to an output of ten volts peak to peak.

Both the preamplifier and the second stage amplifier were powered by a rechargeable battery (figure 3.2).

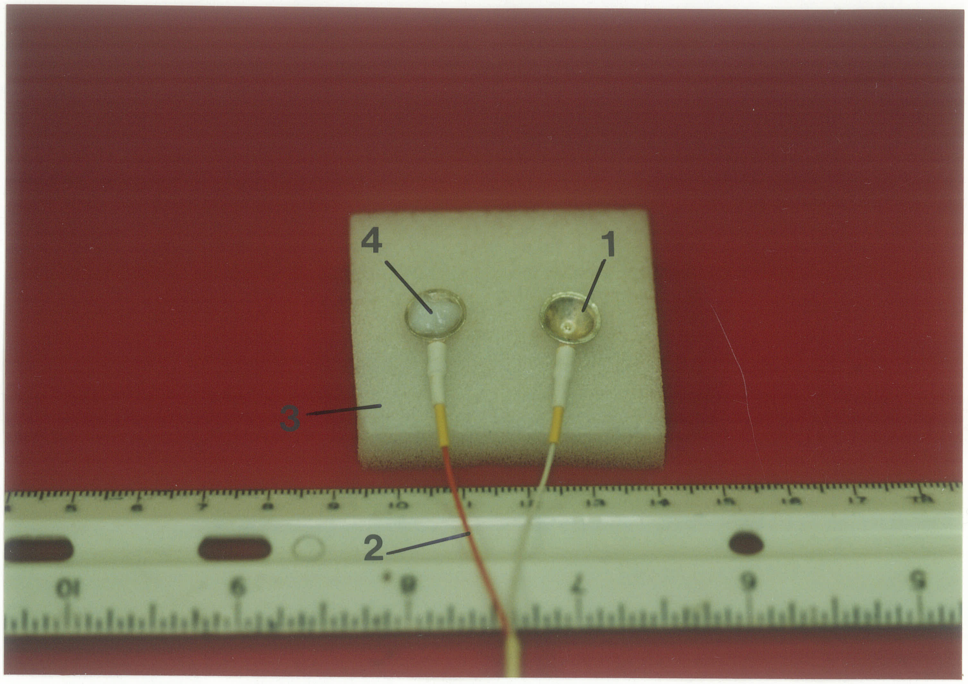


Figure 3.1. Grass Surface Electrodes.

1. Grass silver cup electrode.
2. Wire connecting electrode to preamplifier.
3. Self adhering foam pad.
4. ECG conductor

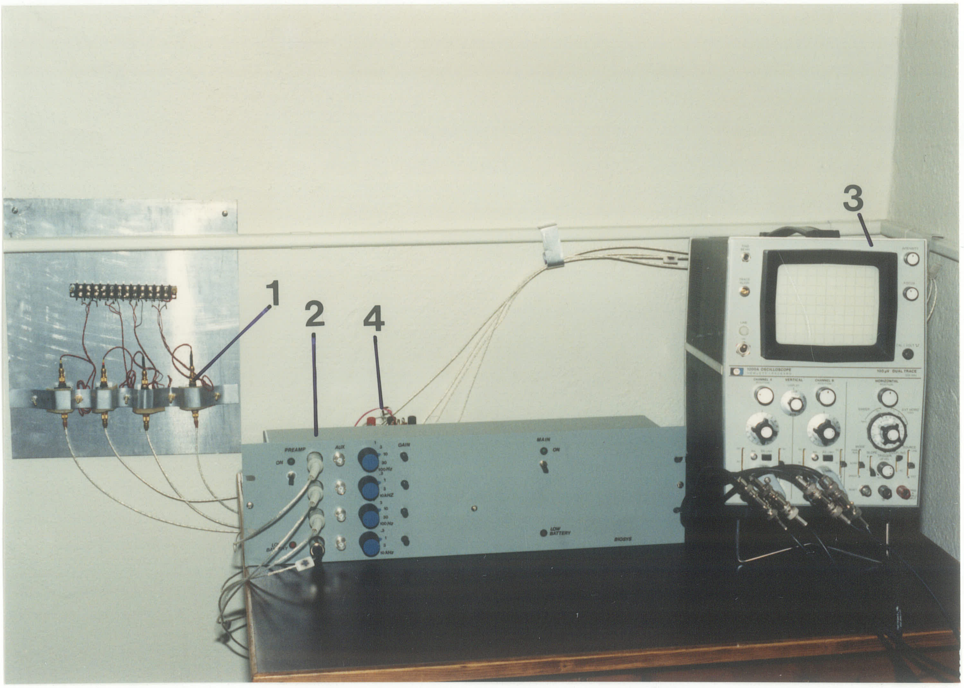


Figure 3.2. EMG Amplifiers, Oscilloscope and Battery.

1. Preamplifier.
2. Second stage amplifier.
3. Oscilloscope.
4. Rechargeable battery.

The output from the second stage amplifier was the final signal generated, and was then directed to a Hewlett Packard Model 1200A dual trace oscilloscope (Figure 3.2) and to a Hewlett Packard 3960 Series Instrumentation Frequency Modulated Tape Recorder (FM tape recorder) where it was recorded on magnetic tape for later replay and further analysis (Figures 3.3).

The oscilloscope was used to provide the operator with continuous visual information about the functioning of the recording apparatus throughout each recording session. It could be switched to show the activities of any two muscles simultaneously.

### C. The Video Apparatus.

A videocamera (Kyocera Finemovie 8, 8 mm Beta) was situated on a tripod in a stationary position approximately 2.5 m from the subject. A 12 inch square mirror was set up at the side of the patient to enable coincidental recordings of both full face and profile images of the subject during each recording session (Figure 3.4). Continuous recordings of head and neck images occurred throughout each experimental session.

### D. The Bite Force Transducer (BFT).

The BFT consisted of a pressure sensitive resistor (PSR) covered on one side by a 1 cm rubber O-ring (Figure 3.5). The rubber ring acted to distribute the force of the bite over a

Figure 3.3. EMG Recording and Analysis Apparatus.

1. FM tape recorder.
2. Analogue to digital converter.
3. IBM compatible microcomputer.

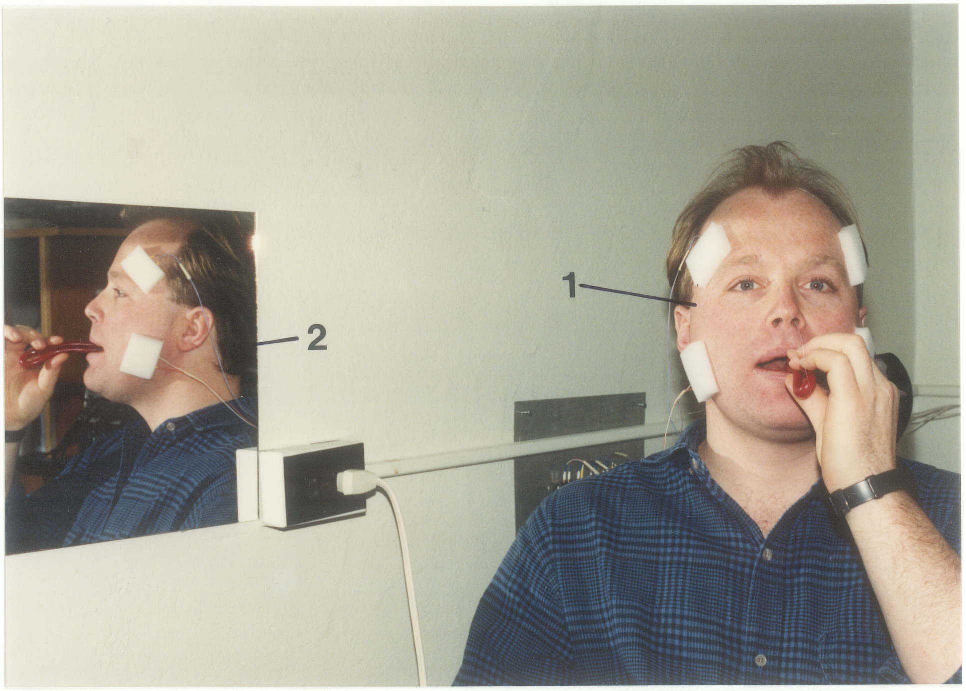


Figure 3.4. Simulation of videotape image of the subject.

1. Full facial view of the subject.
2. Profile image of subject in mirror.

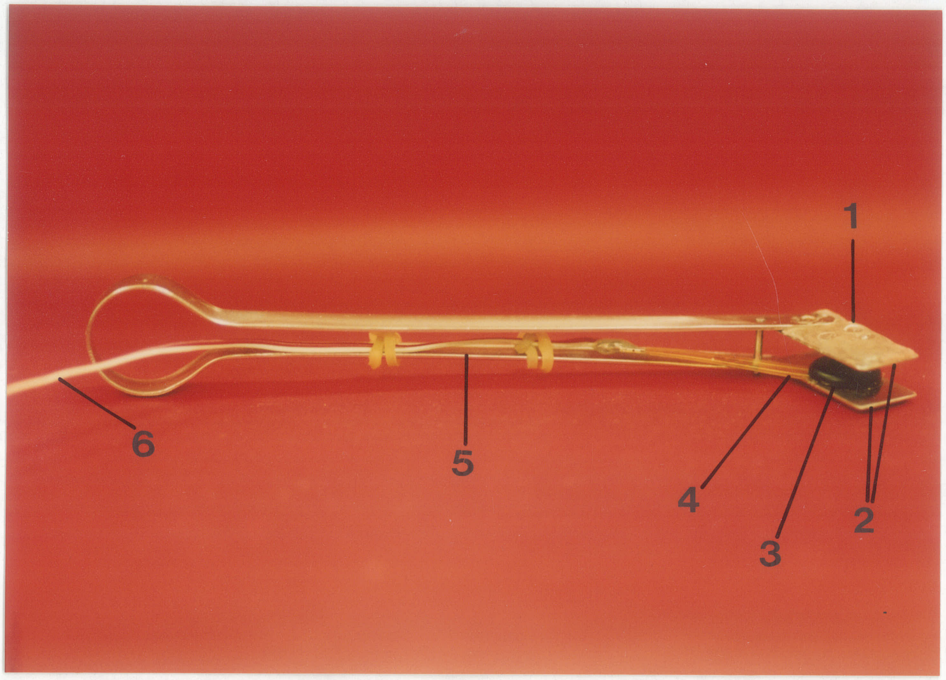


Figure 3.5. Bite Force Transducer.

1. Indexed maxillary bite template.
2. Metal bite platens.
3. Rubber o-ring.
4. Pressure sensitive resistor.
5. Stainless steel handle.
6. Connection to the H.P. multimeter.

greater area of the PSR, resulting in a decrease in stress in any one area of the PSR. This enables the instrument to have greater sensitivity range for monitoring variations in bite force, as fewer areas of the PSR are reaching their maximum stress level. The PSR and attached O-ring were fixed to one of two stainless steel platens between which they, the PSR and O-ring, were sandwiched. The steel platens were permanently attached to a stainless steel handle which acts to maintain a consistent spatial relationship of the platens.

A polymethylmethacrylate maxillary indexed template (bicuspid/cuspid region) was fabricated on the outer surface of the stainless steel platen to which the PSR was not attached. Subject specific study models were used to fabricate each indexed template. A flat acrylic biting surface was fabricated on the outer surface of the other platen fixed to the PSR.

The PSR of the bite force transducer was connected in parallel with a 220 kilo-ohm resistor, and the total resistance was measured by a Hewlett Packard E2377A multimeter.

### E. Recording Procedure.

Prior to each session the subject was positioned in a dental chair, sitting upright and with their head unsupported.

Preparation of the skin for EMG surface electrode application involved identification of the site and direction of the right and left masseter muscles and the right and left anterior temporalis muscles by palpation. The skin over each muscle, and one ear lobe (for the ground) was cleansed using a 30 second wipe with gauze soaked in rubbing alcohol, followed by a 30 second period in which the alcohol was allowed to dry.

Grass silver electrodes were affixed to Reston (TM) self adhering foam pads (3M Co.) at a distance of 25 mm apart, and a small amount of Liqui-cor (Burdick) liquid ECG conductor was applied to each electrode (Figure 3.1). One unit (foam pad and electrodes with conducting paste) was then applied to the prepared skin over each muscle such that the electrode pair was situated over, and ran in the same direction as the body of the muscle (i.e. origin to insertion), and pressed firmly in place (Figures 3.4 and 3.6). The ground consisted of only one electrode affixed to a foam pad that was pressed firmly in place on the prepared earlobe, and held in place with a plastic clip.

The surface impedance of each prepared muscle site was measured using a Hewlett Packard E2377A multimeter. Impedance levels of less than 30 kilo-ohms were considered acceptable and were recorded. If impedance was greater than 30 kilo-ohms, the skin site was prepared again with alcohol and/or different electrode pairs were used until a satisfactory impedance level was achieved, and which was then recorded.

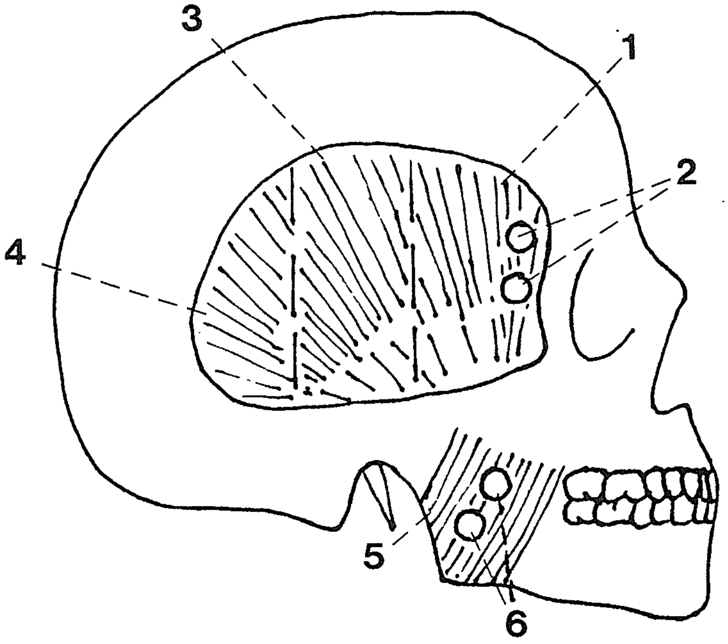


Figure 3.6. EMG Electrode Position.

1. Temporalis muscle: Anterior portion.
2. Surface electrode position on anterior temporalis muscle.
3. Temporalis muscle: Middle portion.
4. Temporalis muscle: Posterior portion.
5. Masseter muscle.
6. Surface electrode position on masseter muscle.

Following EMG electrode placement, subjects were given the following instructions: 1. "For each food sample, you must break off a piece of the sample using your teeth", and the subject was shown how to orient the sample such that incision occurred through a specific dimension of the sample. 2. "After biting off a piece of the food sample, chew the food until it is completely swallowed."

The food samples were presented to the subjects in a manner which ensured that each subject understood which dimension of the sample to bite through.

The experimental session involved simultaneous videotape and EMG recording of each subject. The videotape recording was continuous throughout each data collection session.

EMG signals were recorded on the FM tape recorder while the patient incised various food samples. The food samples consisted of 4 food groups, which included 2 food types; brittle, and resilient (carrot and licorice respectively) and 2 thickness of each food type (2.0 millimetres and 20 millimetres and, 5.0 millimetres and 15.0 millimetres respectively) (Figure 3.7). The subject incised, chewed and swallowed 5 samples from each of the food groups. Therefore, 20 trials were recorded for each subject at each experimental session.

Following the food tasks, EMG signals were recorded during right side and left side isometric biting on the BFT. Separately, the right and left indexed maxillary platen of the

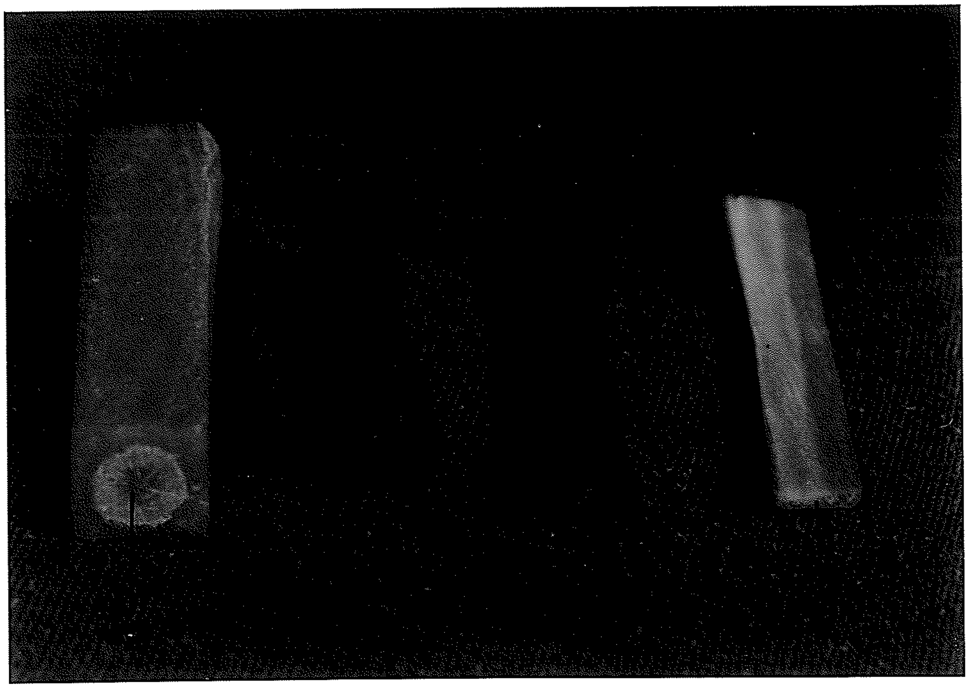


Figure 3.7. Food Samples

1. 2 mm Carrot.
2. 20 mm Carrot.
3. 5 mm Licorice.
4. 15 mm Licorice.

BFT was fitted to the maxillary teeth and the subject was then asked to close their lower teeth onto the flat bite pad in order to support the BFT. Subjects were then asked to increase the level of their bite force (i.e. bite harder) on the BFT until an observable level of EMG activity was visible on the oscilloscope in all four channels. This was always a submaximal bite force level, and the corresponding resistance level was measured with the multimeter and was recorded.

EMG recordings were made while the patient was asked to repeat the identical submaximal bite 5 times on the right side and 5 times on the left side. Subjects were instructed by the experimenter to increase or decrease bite force in order to repeat the specific metered resistance level.

### F. Bite Force Transducer Calibration.

After each recording session the BFT was calibrated. Separately, the right and then the left, maxillary and mandibular quadrant model pairs were fixed with two sided tape to the metal plates of a Houndsfield tensometer (Figure 3.8). The mandibular model was placed 2 mm lateral to centric occlusion position. The appropriate BFT was introduced interocclusally such that the indexed platen fitted over the teeth of the maxillary model. The models were approximated producing a force which was then increased to produce an identical metered resistance level from the BFT that was produced during each recording session.

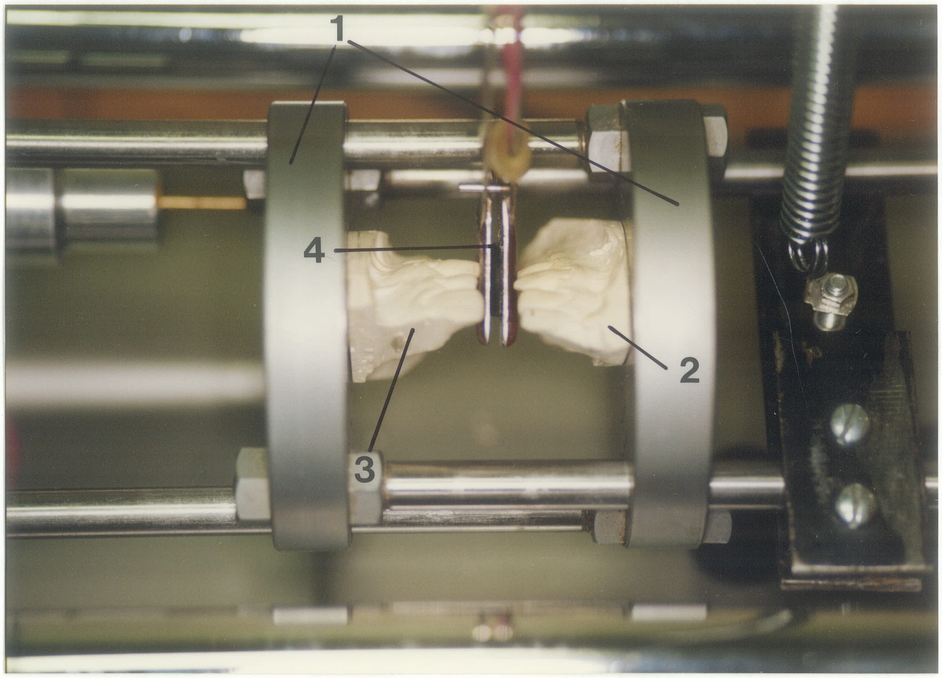


Figure 3.8. Quadrant Models mounted on the Tensometer

1. Metal plates of the tensometer.
2. Mounted maxillary left quadrant model.
3. Mounted maxillary right quadrant model.
4. Bite force transducer.

The measured force level from the tensometer was recorded. Force levels were reduced to a level of less than two pounds, and then reapplied to the recording session level. Five force readings were made from the tensometer for the given metered resistance level observed during the recording session.

### G. Quantitative EMG Analysis.

Using the FM tape recorder, an analogue to digital converter and an IBM compatible microcomputer, the EMG signal recordings were converted from analogue format on magnetic tape to digital format and saved on the hard disk drive of the microcomputer (Figure 3.4). Once in digital format a program was used to display all four muscle recordings for each food sample trial.

Using both video and EMG recordings, time sequencing of specific masticatory activities could be defined. The time period of the following two specific activities were further analyzed: (1) Incision and; (2) Incision and chewing of the food sample, until the first swallow occurred but not including the first swallow.

Using another computer program, each digitized sample of the EMG signals was squared, resulting in only positive EMG values. The area under the squared EMG signals were then determined by integration over the specific time period identified from the videorecordings and EMG recordings. The resultant time dependant integrated squared (ISq) EMG values were expressed in units of volts squared-seconds.

The energy from a simple electric circuit is equal to $\int P\, dt$ (P=power, t =time). Power is equal to $v^2/R$ (v=voltage, R=resistance) and is equal to i*v (i=current). The voltage, current and resistance can be measured in a circuit using an appropriate meter. The resistance offered by any resistor can be determined indirectly by short circuiting the resistor. The resultant decrease in resistance (or resistance offered when the resistor is left out of the circuit) can be calculated once the difference in power between the circuits is determined. The proportion of the energy of the circuit with both resistors to the energy in the circuit with only one resistor is an indication of the relative efficiency of one circuit to the other.

It is assumed that the integrated square EMG is a linear measure of the energetic profile of the muscle. During isometric bite force the ISq EMG is a measure of energy reflecting only the internal resistance of the muscle (i.e short circuit). However, during varimetric contractions of the muscle the ISq EMG is a measure of muscle energy reflecting both internal resistance of the muscle and the resistance offered by an external source.

The ratio of energy required to overcome the combined external resistance and internal resistance over the energy required to overcome the internal resistance alone is a measure of the efficiency of the muscle in question for a given task. A sum of the ratios for the masseter and anterior temporalis muscles may well reflect the efficiency of the masticatory muscle system.

Thus the system efficiency can be compared within individuals to assess differences in masticatory energetic efficiency between tasks. Also, this assessment of the masticatory energetic efficiency can be used to compare between individuals.

For this study, ISq EMG per lb. of isometric bite forces per second were determined for each of the four masticatory muscles recorded. ISq EMG was derived for a one second interval for each of the five trials for each of the right and the left BFT. Mean ISq EMG values were then divided by the average bite force as measured by the tensometer using the BFT. Mean right and left ISq EMG/sec/lb were summed and the total was considered one EMG Bite Force Equivalent (BFE) for the specific muscle for the specific individual.

ISq EMG from each of the four muscles for each masticatory task for each trial for each individual were determined. Each of the results were then divided by the ISq for one BFE (determined above) for that specific muscle for that specific individual producing a BFE value for each muscle for each task. The BFE values for all muscles for each task were summed giving the total BFE for that trial. Total BFE values between subjects were used for comparison and statistical analysis.

## H. Measurement of Error.

### 1. Investigator Error.

As part of the main investigation, two supplementary studies were undertaken to assess measurement error involved in 1) the calibration of the bite force transducer, 2) identification of the various masticatory activities from EMG and video recordings.

a. Supplementary Study 1.

The first study examined measurement error on the part of this investigator in orienting the study models on the Houndsfield tensometer in a standardized manner. The maxillary and mandibular study models, from the left side of one subject, were mounted on the tensometer on three separate occasions. With each mounting the appropriately indexed BFT was inserted between the occluding surfaces of the teeth. The applied force was increased to a metered resistance level of 2 kilo-ohms. The corresponding force level was read from the tensometer and was recorded. Force level was reduced to 0 pounds. The force was then reapplied in the manner described above. Five sets of recordings were made at each of the three sessions.

Means and standard deviations were calculated to determine the degree of investigator error.

b. Supplementary Study 2.

The second study examined measurement error on the part of this investigator in identifying the various masticatory activities (incision and, incision and chewing to first swallow) from the EMG and video recordings. The integrated squared EMG was determined on three separate occasions (at least one week apart) for one trial (typical EMG recording) for each of two of the subjects. Five measurements were made for both, the task of incision alone, and the combined task of incision and chewing until the first swallow at each session.

Means and standard deviations were calculated to determine the degree of investigator error.

### 2. Bite Force Transducer Linearity.

The linearity of the bite force transducer was established by mounting the models of one subject (E.P.) on the Houndsfield tensometer in the manner described in section F. The BFT was introduced interocclusally and the tensometer force was increased. Several force levels in the 0 to 40 lb. range were recorded along with their metered resistance levels. The data were plotted, and the linear range of the BFT was determined visually from the plot. The correlation coefficient for the linear relationship of the data within the chosen linear range of the BFT was then calculated, and tested for significance.

It is important to note that the linearity of the BFT was not of great significance in this study. The BFT was used to measure one specific calibration bite force for each subject. The reproducibility of measuring a specific bite force using the BFT was investigated in Supplementary Study 2, above. For the purpose of this study it is best if BFT measurements are made in the relatively unsteep range of the apparatus. This will produce more accurate force measurements with the BFT.

### I. Statistical Analysis.

Means and standard deviations in Bite Force Equivalents were calculated for the tasks of; incision, incision and chewing, and incision as a proportion of incision and chewing were calculated for each food group, for each subject.

AOB and non-AOB group means and standard deviations were then determined.

The individual means were then subjected to a mixed analysis of variance.

Correlation coefficients were calculated between food dimensions and group BFE values.

# Results

## A. Overview

The data were collected in two primary forms: 1. EMG recordings and; 2. videorecordings. The EMG data for all subjects was converted from ISq EMG to BFE units, using the subject specific BFT data, so that comparisons could be made between subjects. Therefore BFE values were assigned for each trial. The BFE values were then used for statistical analysis.

Videorecording data was observed to assess qualitative variation, within subjects and within groups, during the incision phase of mastication.

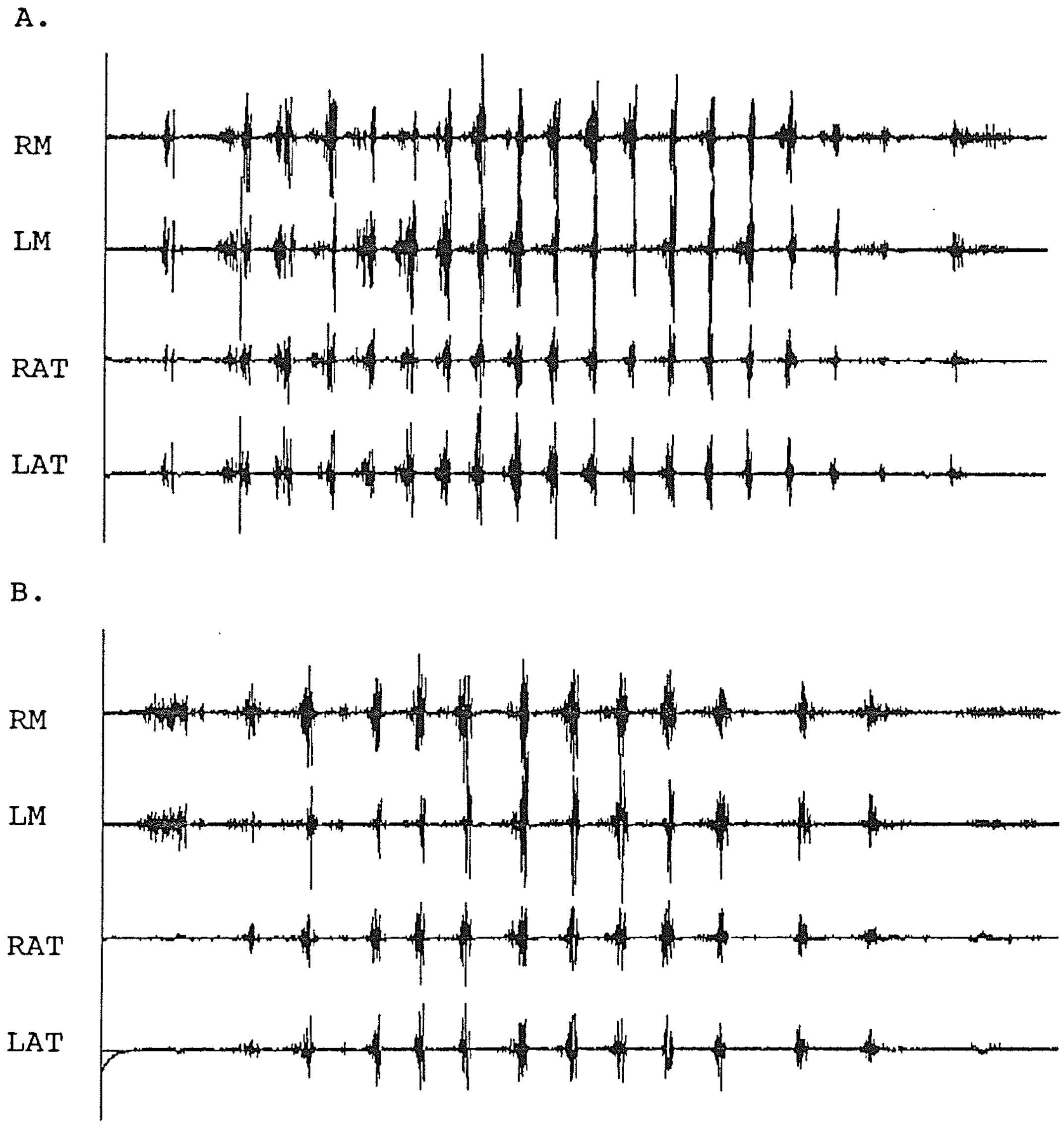
The results will be presented in the following format:

1. Presentation of individual subject EMG and videorecording data, including mention of the relationship between the two (i.e. EMG and videorecording).
2. Presentation of group (AOB versus non-AOB) data.
3. Presentation of data from the studies of investigator error and the study of BFT linearity.

## B. Subject Specific Results

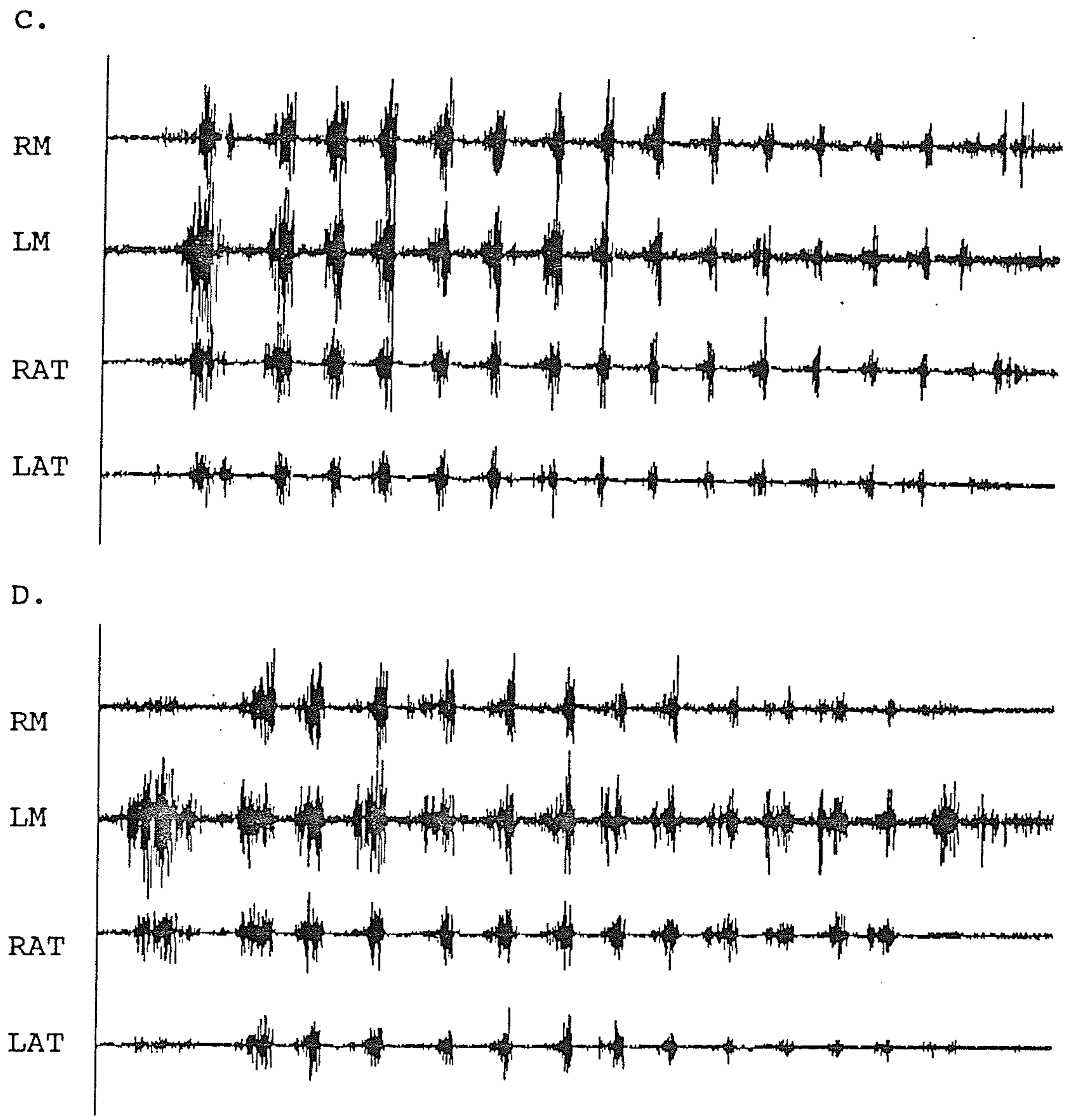
Sample EMG tracings are illustrated in Figure 4.1. The specific masticatory phases of incision, chewing and swallowing are identified on each tracing.

Figure 4.1 Sample EMG Tracings.



1. Incision phase
2. Chewing phase
3. Swallowing phase.

Note: RM = Right masseter muscle.
LM = Left masseter muscle.
RAT = Right Anterior temporalis muscle.
LAT = Left Anterior temporalis muscle.



1. Incision phase
2. Chewing phase
3. Swallowing phase.

Note: RM = Right masseter muscle.
LM = Left masseter muscle.
RAT = Right Anterior temporalis muscle.
LAT = Left Anterior temporalis muscle.

Integrated squared EMG data were derived using a computer program. Total BFE were then calculated for each trial. The mean and standard deviation for the masticatory phase of incision alone, and for the combined masticatory phases of incision and chewing until first swallow but not including the swallow were calculated for each subject for each food sample. These results are listed in Tables 4.1 and 4.2. Also, the mean and standard deviation for the proportional contribution of the masticatory phase of incision to the combined masticatory phases of incision and chewing (I/IC) are presented in Table 4.3.

1. Non-AOB Subjects.

a. Subject M.C.:

The EMG data from the incision phase of mastication suggests a greater between-trial variability for carrot samples of both dimensions than for either of the licorice samples (Table 4.1). The videorecording observations found that subject M.C. used his central incisor teeth for incision throughout all the trials. Specifically, subject M.C. incised with two very different patterns during the 2 mm carrot trials. The first pattern involved securing the carrot between the incisors and using a lateral hand motion to break the sample. The other pattern, observed in the second trial only, involved using only the incisors and no noticeable hand motion to break the food sample. This second trial also had the

Table 4.1. Individual Subject Energy Values for the Task of Incision.

| | Task | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Carrot 2 mm | | Carrot 20 mm | | Licorice 5 mm | | Licorice 15 mm | |
| Subject | Mean˜ | S.D.˜ | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| M.C. * | 27.69 | 24.40 | 58.67 | 21.58 | 24.52 | 5.92 | 63.17 | 6.83 |
| G.H. * | 3.63 | 3.43 | 35.75 | 5.99 | 2.76 | 0.63 | 27.63 | 5.73 |
| R.K. * | 6.14 | 0.91 | 78.02 | 29.92 | 14.14 | 4.58 | 53.02 | 8.71 |
| E.P. * | 46.44 | 28.41 | 268.7 | 68.41 | 58.12 | 14.80 | 161.61 | 61.41 |
| L.M. + | 17.68 | 8.84 | 47.87 | 16.45 | 52.51 | 14.22 | 65.51 | 32.08 |
| P.S. + | 33.67 | 17.01 | 94.14 | 25.76 | 91.81 | 19.36 | 121.21 | 38.67 |
| T.S. + | 20.84 | 9.55 | 25.17 | 9.28 | 47.75 | 12.18 | 58.69 | 61.17 |
| M.W. + | 55.36 | 34.46 | 52.55 | 7.39 | 9.22 | 1.76 | 26.70 | 7.45 |

* non-AOB
\+ AOB
˜ note: Energy values reported are in units of Bite Force Equivalents.

Table 4.2. Individual Subject Energy Values for the Combined Tasks of Incision and Chewing.

| Subject | Task | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Carrot 2 mm | | Carrot 20 mm | | Licorice 5 mm | | Licorice 15 mm | |
| | Mean˜ | S.D.˜ | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| M.C. * | 1410.63 | 333.83 | 3664.65 | 568.10 | 1838.48 | 236.07 | 4006.45 | 365.65 |
| G.H. * | 283.42 | 91.66 | 1650.82 | 291.47 | 589.86 | 77.90 | 1887.08 | 437.79 |
| R.K. * | 301.09 | 12.35 | 1283.44 | 274.38 | 705.89 | 80.70 | 1473.86 | 295.49 |
| E.P. * | 823.21 | 150.38 | 2982.87 | 528.71 | 2157.68 | 275.97 | 2596.74 | 260.26 |
| L.M. + | 268.81 | 71.57 | 1525.12 | 195.35 | 450.50 | 79.66 | 814.26 | 135.53 |
| P.S. + | 536.60 | 161.92 | 5957.42 | 680.46 | 1333.38 | 278.49 | 3452.43 | 848.90 |
| T.S. + | 246.52 | 34.94 | 1208.99 | 397.84 | 348.07 | 76.46 | 1199.89 | 297.23 |
| M.W. + | 398.45 | 274.02 | 1119.97 | 117.47 | 236.03 | 47.64 | 567.89 | 163.72 |

* non-AOB
\+ AOB
˜ note: all energy values are in units of Bite Force Equivalents.

Table 4.3. Individual Subject Proportion Values for the Task of Incision Energy as a Proportion of the Combined Tasks of Incision and Chewing Energy.

| | Task | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Carrot 2 mm | | Carrot 20 mm | | Licorice 5 mm | | Licorice 15 mm | |
| Subject | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| M.C. * | 0.020 | 0.014 | 0.016 | 0.006 | 0.014 | 0.005 | 0.016 | 0.003 |
| G.H. * | 0.018 | 0.024 | 0.022 | 0.005 | 0.005 | 0.001 | 0.015 | 0.003 |
| R.K. * | 0.021 | 0.004 | 0.068 | 0.036 | 0.020 | 0.006 | 0.036 | 0.002 |
| E.P. * | 0.056 | 0.029 | 0.089 | 0.013 | 0.028 | 0.009 | 0.062 | 0.022 |
| L.M. + | 0.063 | 0.016 | 0.032 | 0.013 | 0.115 | 0.018 | 0.077 | 0.026 |
| P.S. + | 0.070 | 0.041 | 0.016 | 0.003 | 0.070 | 0.014 | 0.036 | 0.013 |
| T.S. + | 0.084 | 0.038 | 0.025 | 0.014 | 0.143 | 0.043 | 0.056 | 0.066 |
| M.W. + | 0.192 | 0.121 | 0.048 | 0.011 | 0.040 | 0.008 | 0.049 | 0.011 |

* non-AOB
\+ AOB

greatest BFE value for 2 mm carrot trials for this subject.

There were no obvious differences observed in the incision pattern between 20 mm carrot trials. No differences were observed between the five trials of either of the licorice samples as well.

The combined tasks of incision and chewing show a specific pattern for subject M.C. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension trials. Licorice trials required more energy on average than the similar dimension carrot trials.

For subject M.C., I/IC values were greatest on average in the 2 mm carrot group, less in the 20 mm carrot and 15 mm licorice groups and, least in the 5 mm licorice group (Table 4.3).

b. Subject G.H.:

The EMG data suggests greatest variability within the 2 mm carrot trials for subject G.H. (Table 4.1). The other food samples showed less variability. Three distinct patterns of incision were observed in the 2 mm carrot trials. One pattern, occurring in the first trial only, involved two sequential bites. The second pattern, occurring in only the fourth trial, involved two sequential bites, and following these the subject used hand motion to tear the carrot laterally in order to effect the final fracture. The final pattern, occurring in the remaining trials, involved only a single bite. The fourth trial, associated with the second pattern described, had the greatest energy value (250% greater than the next greatest value) of the five trials.

There were also three different incision patterns observed in the 20 mm carrot trials. The first trial involved incision in the left cuspid region, and was associated with the lowest energy values. The second and third trials involved incision in the right central incisor region. The fourth and fifth trial involved incision in the midline region. There was no suggestion of differences in the energy values between the final two incision patterns observed.

Incision during the 5 mm licorice trials took two discrete patterns. One pattern occurred in the first three trials. This involved incision in the left central incisor region, with some hand motion involved in pulling on the food sample. The final two trials involved incision in the right cuspid region, with the subject using hand motion to pull the licorice straight out from his mouth. The EMG data shows the two lowest values for incision of 5 mm licorice samples to be those associated with the final two trials.

Subject G.H. alternated sides for incision, from right to left, between each of the 15 mm licorice trials. The licorice was held with two hands and was incised in the right or left cuspid region, starting in the first trial on the left side. The EMG data showed an alternating pattern of energy values throughout the trials as well.

The combined tasks of incision and chewing show a specific pattern for subject G.H. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension food trials. Licorice trials required more energy on average than the similar dimension carrot trials.

For subject G.H., I/IC values were greatest on average in the 20 mm carrot group, less in the 2 mm carrot and 15 mm licorice groups and least in the 5 mm licorice groups (Table 4.3).

c. Subject R.K.:

The EMG data suggest greatest variation in the 20 mm carrot and 5 mm licorice trials for subject R.K. (Table 4.1). Two patterns of incision were observed from the videorecordings during the 2 mm carrot trials. One pattern, observed, in only the first trial, involved incision in the bicuspid region. The pattern in the remaining trials involved incision by the central incisors. The first trial, associated with the first incision pattern described , had the greatest energy value of any of the 2 mm carrot trials.

Three incision patterns were observed for the 20 mm carrot sample for this subject. The first pattern, observed in only the first trial and, associated with the lowest BFE value, involved incision with the central incisors. The remaining incision patterns for the 20 mm carrot sample occurred in the cuspid and bicuspid region. The first of these patterns involved orientation of the food sample perpendicular to the labial surface of the teeth. The other bicuspid region patterns involved presentation of the carrot sample in an anteroposteriorly oblique orientation relative to the labial surfaces of the teeth. Notably, the fourth trial involved the perpendicular orientation of the carrot, as described above, but also involved two bites to break the carrot. This fourth trial had the greatest energy value of any of the 20 mm carrot trials.

Two patterns of incision were observed during the 5 mm licorice trials. In the first trial, incision occurred in the central incisor region. During all subsequent trials, incision occurred in the cuspid region. The first trial was also associated with the greatest BFE value of the five trials.

The 15 mm licorice trials involved two different patterns of incision. The first trial involved an anteroposteriorly oblique presentation of the food to the cuspid region. Subsequent trials appeared to have a more perpendicular presentation in the cuspid region. However some subtle variations in the anteroposterior angular presentation of the food to the cuspid region may have existed, but were difficult to observe. The first trial, associated with the unique incision pattern described above, had the greatest energy value of the five trials.

The combined tasks of incision and chewing show a specific pattern for subject R.K. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension trials. Licorice required more energy on average than the similar dimension carrot.

For subject R.K., I/IC was greatest on average in the 20 mm carrot group, less in the 15 mm licorice group and least in the 5 mm licorice group and the 2 mm carrot group (Table 4.3).

d. Subject E.P.:

The EMG data, from subject E.P., suggest greatest variability in the 2 mm licorice and 15 mm licorice trials (Table 4.1). Several incisive patterns were observed during the 2 mm carrot trials. One pattern, occurring in the first two trials, involved a two phase incision in the cuspid region, the first trial appearing to have greater lateral hand motion involvement than the second trial. The final three trials involved incision in the bicuspid region. Also, the first trial had the greatest energy value of the five trials. The fourth trial had the lowest energy value but this was not associated with any unique pattern of incision.

The 20 mm carrot trials involved a progressive change in the positioning of the sample from anterior (cuspid region) to posterior (bicuspid region), and a progressive increase in the anteroposterior obliqueness of the food presentation relative to the labial surfaces of the teeth. The EMG data were found to show an associated progressive decrease in energy values from the second to the fifth trial.

The were no observable differences found between the 5 mm licorice trials, all occurring in the first bicuspid region. The EMG data indicates that the fifth, 5 mm licorice trial had the greatest energy value, however this was not associated with a unique pattern of incision.

Two patterns of incision were observed during the 15 mm licorice trials. The initial two trials involved incision in the right cuspid region. The subsequent three trials also involved incision in the right cuspid region, but displayed a noticeable change in hand position on the licorice, and a noticeable alteration of the head position each time incision occurred. The EMG data reflect this change in pattern as well. The first two trials had energy values 100% greater than those in the last three trials.

The combined tasks of incision and chewing show a specific pattern for subject E.P. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension trials. The small dimension licorice trials required more energy on average than the similar dimension carrot trials. However, the larger dimension carrot trials required more energy on average than the similar dimension licorice trials.

For subject E.P., I/IC values were on average greatest in the 20 mm carrot group, less in the 15 mm licorice group and 2 mm carrot group and least in the 5 mm licorice group (Table

4.3).

2. AOB Subjects

a. Subject L.M.:

The EMG data from subject L.M. displayed the greatest variation during the 2 mm carrot and 15 mm licorice trials (Table 4.1). There were no observable differences in the pattern of incision throughout the 2 mm carrot trials. Each involved incision with the right bicuspid teeth. From the EMG data, the first trial had an energy value 100% greater than any of the four subsequent trials, but this was not associated with any unique pattern of incision.

All of the 20 mm carrot trials involved incision in the left cuspid region. The first and fourth trial required two biting attempts, the third trial required three biting attempts, and the second and fifth trial involved only one biting attempt. Although, the second trial involved one long bite and the fifth trial involved a bite phase followed by a pausing phase. The fifth trial also had greatest energy value of the five trials.

All of the 5 mm licorice trials involved incision in the left bicuspid region with hand motion involved in pulling the sample away. It appeared that the hand involvement increased in magnitude throughout the trials. EMG data showed greatest energy values in the first trial, similar energy values in the subsequent three trials, and the lowest energy values in the final trial. These progressive energy level decreases may be associated with the progressive increase in hand involvement throughout the trials.

All of the 15 mm licorice trials had similar patterns of incision. This pattern involved incision in the left bicuspid region together with a pulling motion on the licorice sample. The EMG data indicates the first two trials had much higher energy values than the subsequent three trials. However, these reported differences in energy values were not associated with any unique patterns of incision.

The combined tasks of incision and chewing show a specific pattern for subject L.M. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension food trials. The small dimension licorice trials required on average more energy than the small dimension carrot trials. However, the large dimension carrot trials required on average more energy than the similar dimension licorice trials

For subject L.M., I/IC values were on average greatest in the 5 mm licorice group, less in the 15 mm licorice group and 2 mm carrot group and, least in the 20 mm carrot group (Table 4.3).

b. Subject P.S.:

EMG data from subject P.S. shows greatest variation in the 2 mm carrot trials and 15 mm licorice trials (Table 4.1).

Two patterns of incision were observed during the 2 mm carrot trials. All trials involved incision with the central incisor teeth. The first two trials involved one hand position on the carrot, and the latter three trials involved a change of hand position, to an overhand (palm facing downward) grip. The energy required for incision had an associated increase between the first two and latter three trials as well.

Similarly, all 20 mm carrot trials involved incision with the central incisors. Subject P.S. changed his grip for the third and the fourth trials. These trials (third and fourth) had greater energy values than the other three trials.

All of the 5 mm licorice displayed similar incision patterns, each involving incision with the central incisors, and the use of hand motion to pull on the licorice. The EMG data had a change in energy values between the second and third trials. However, this change was not associated with a change in incision pattern.

The five 15 mm licorice trials had similar patterns of incision, all involving the central incisors. There appeared to be a variation in the amount of masticatory effort, this being least in the fifth trial. In the first trial the incision pattern also involved a hand pulling motion on the food sample. The second trial had the greatest energy value from the EMG data, however this difference was not associated with a unique pattern of incision. The lowest BFE value occurred in trial 5, where masticatory effort appeared to be least.

The combined tasks of incision and chewing show a specific pattern for subject P.S. (Table 4.2). The larger dimension food trials required on average more energy than the smaller dimension trials. Licorice trials required on average more energy than the similar dimension carrot trials.

For subject P.S., I/IC was greatest on average in the 5 mm licorice group and 2 mm carrot group, was less in the 15 mm licorice group and least in the 20 mm carrot group (Table 4.3).

c. Subject T.S.:

EMG data for subject T.S. displayed the greatest variation in the 2 mm carrot trials and 15 mm licorice trials (Table 4.1). Two patterns of incision were apparent in the 2 mm carrot trials. One pattern, occurring in only the first trial involved holding the food between the incisors and using hand motion to tear the food. The remaining trials involved incision in the right bicuspid region. The fifth trial, occurring in the right bicuspid region, involved some levering hand motion. The energy value for the first trial was approximately 10% of any of the subsequent 2 mm carrot trials.

The 20 mm carrot trials were all very similar. The carrot was stabilized between the anterior teeth and hand motion was used to lever the food upward. EMG data indicates that the first 2 trials had lower energy values than the subsequent 3 trials. However, there was no obvious difference in the incision patterns between these two groups of trials.

All of the 5 mm licorice trials had similar patterns of incision. Each involved securing the licorice between the right bicuspid teeth, and using hand motion to pull the licorice forward until it broke. Energy values for all but the second trial were similar. However, the dissimilar second trial was not associated with any unique patterns of incision.

The 15 mm licorice trials had two distinct patterns. Four of the trials involved holding the licorice between the anterior teeth, and then using hand motion to pull on the licorice until it broke. The third trial involved similar hand involvement to the other trials, but the food was held in the right bicuspid area, rather than incisor area. The third trial also had an energy value 300% greater than the next largest energy value in the 15 mm licorice trials.

The combined tasks of incision and chewing show a specific pattern for subject T.S. (Table 4.2). The larger dimension food trials required on average more energy than the smaller dimension trials. Small dimension licorice trials required more energy on average than the small dimension carrot trials. However, the large dimension carrot trials required more energy, on average, than the larger dimension licorice trials.

For subject T.S., I/IC was on average greatest in the 5 mm licorice group, less in the 2 mm carrot group, even less in the 15 mm licorice group and least in the 20 mm carrot group (Table 4.3).

d. Subject M.W.:

The EMG data for subject M.W. showed greatest variation in the 2 mm carrot trials (table 4.1). The 2 mm carrot trials involved several different incision patterns. One pattern, occurring in the first trial only, involved holding the carrot between the incisors and using hand motion to pull the carrot straight out from the mouth. The remaining samples involved holding the carrot with the incisors, and the use of hand motion to pull or tear the carrot in various directions. The greatest energy values occurred in the third and the fifth trials. It was only in these trials that the carrot was torn with hand motion in order to finally break it.

The 20 mm carrot trials involved the use of the incisors to break the carrot. During the third trial, the final activity was a small hand motion used to tear the remaining unbroken carrot. Variation in energy values were not associated with any change in incision pattern.

The five, 5 mm licorice trials for subject M.W. showed a common pattern of incision. The pattern involved holding the licorice with the central incisors and then using hand motion to pull on the licorice to effect the break. Energy values were also consistent between all five trials.

The 15 mm licorice trials involved two patterns. The pattern used during the first trial involved securing the licorice with the anterior teeth and then using hand motion to tear the licorice to the left. The other trials involved holding the licorice with the incisors and using hand motion to pull on the licorice until it broke. The first trial also had the greatest energy value of the five, 15 mm licorice trials.

The combined tasks of incision and chewing show a specific pattern for subject M.W. (Table 4.2). The larger dimension food trials required more energy on average than the smaller dimension trials. Licorice trials required less energy on average than the similar dimension carrot trials. For subject M.W., I/IC values were on average greatest in the 2 mm carrot group, less in the 15 mm licorice group and the 20 mm carrot group and were least in the 5 mm licorice group (Table 4.3)

## C. Group Results

A summary of AOB versus the non-AOB group means are listed in Tables 4.4, 4.5 and 4.6, and are illustrated in Figures 4.2, 4.3 and 4.4 for the task of incision alone, the combined tasks of incision and chewing and, incision as a proportion of the masticatory cycle to first swallow (I/IC), respectively.

The data were subjected to a mixed analysis of variance to evaluate differences between AOB and non-AOB groups, food

Table 4.4. Group Energy Values for the Task of Incision.

| Food Type | non-AOB |  | AOB |  |
|---|---|---|---|---|
|  | Mean~ | S.D. | Mean | S.D. |
| Carrot 2 mm | 20.97 | 17.43 | 31.88 | 14.82 |
| Carrot 20 mm | 110.29 | 92.69 | 54.93 | 24.89 |
| Licorice 5 mm | 24.88 | 20.67 | 50.32 | 29.25 |
| Licorice 15 mm | 76.36 | 50.90 | 68.03 | 34.02 |

Table 4.5 Group Energy Values for the Combined Tasks of Incision and Chewing.

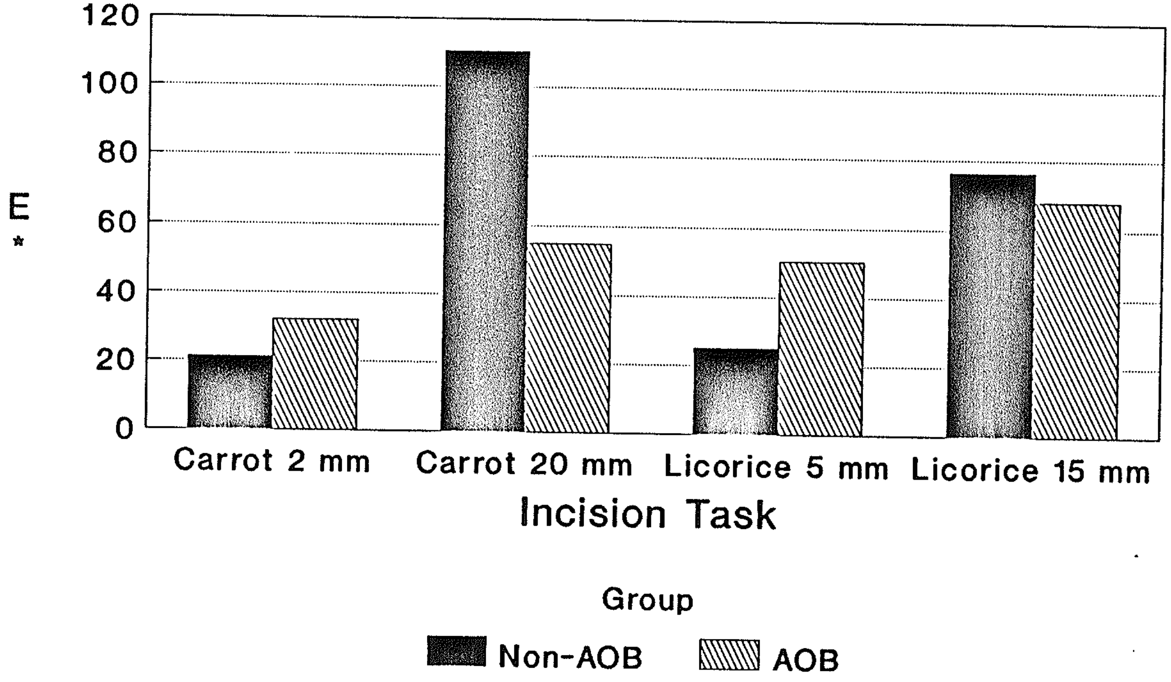
| Food Type | non-AOB |  | AOB |  |
|---|---|---|---|---|
|  | Mean~ | S.D. | Mean | S.D. |
| Carrot 2 mm | 704.59 | 461.73 | 362.60 | 116.01 |
| Carrot 20 mm | 2395.45 | 967.86 | 2452.88 | 2028.94 |
| Licorice 5 mm | 1322.98 | 685.70 | 592.00 | 434.71 |
| Licorice 15 mm | 2491.03 | 962.69 | 1508.62 | 1144.64 |

~Note : Energy values in units of Bite Force Equivalents

Table 4.6. Group Proportion Values for the Task of Incision as a Proportion of the Combined Tasks of Incison and Chewing

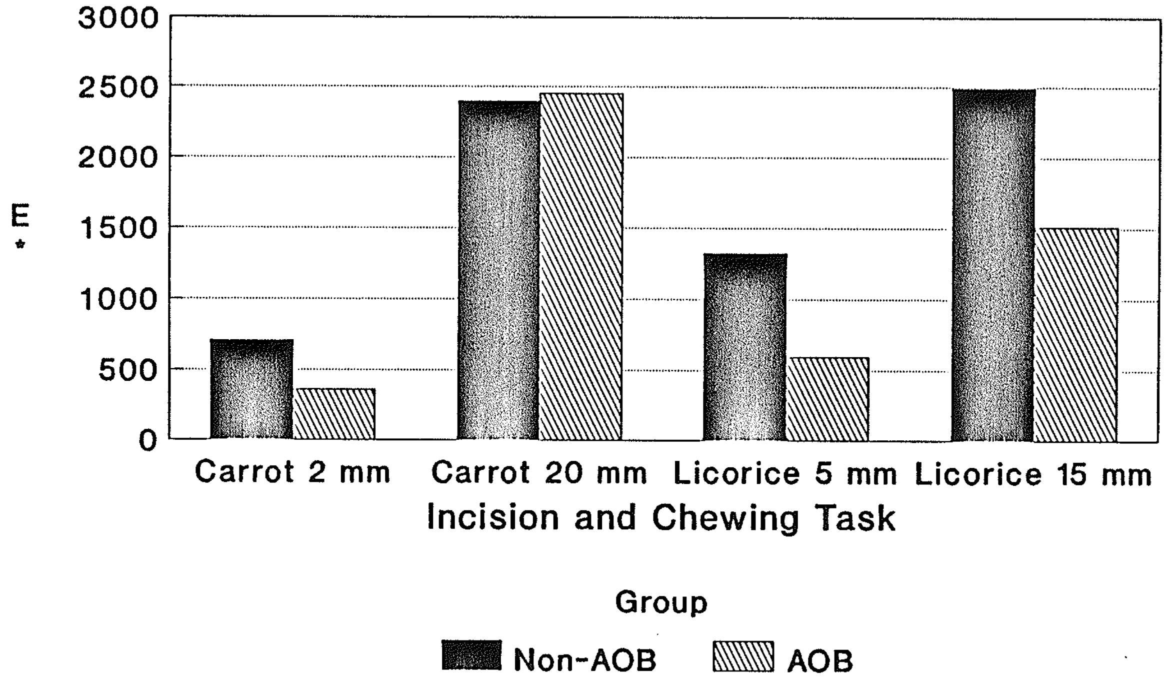
| Food Type | non-AOB |  | AOB |  |
|---|---|---|---|---|
|  | Mean | S.D. | Mean | S.D. |
| Carrot 2 mm | 0.029 | 0.016 | 0.102 | 0.052 |
| Carrot 20 mm | 0.049 | 0.031 | 0.030 | 0.012 |
| Licorice 5 mm | 0.017 | 0.008 | 0.092 | 0.040 |
| Licorice 15 mm | 0.032 | 0.019 | 0.055 | 0.015 |

Figure 4.2
Relationship of Incision Task to Energy for Non-AOB and AOB Subjects



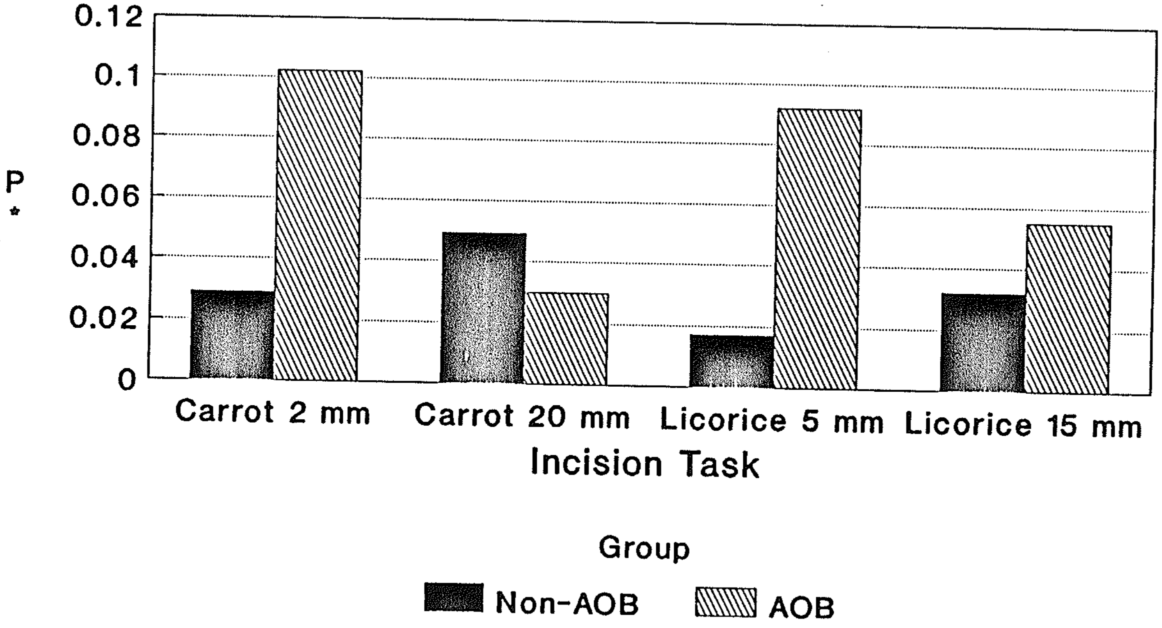
* E is energy in Bite Force Equivalents

Figure 4.3 Relationship of Combined Tasks of Incision and Chewing to Energy for Non-AOB and AOB Subjects.



* E is Energy in Bite Force Equivalents

Figure 4.4
Relationship of Incision Task to I/IC
Values in Non-AOB and AOB Subjects



(*) P is the energy (in BFE) for incision as a proportion of the energy (in BFE) for incision and chewing.

groups and for interactions between these (food and open bite status). The results of the mixed analysis of variance comparing incision, combined incision and chewing and, I/IC are summarized in Tables 4.7, 4.8 and 4.9 respectively.

Correlation coefficients were calculated for the relationship between food dimension and BFE values from the various masticatory tasks and between food dimension and I/IC values. The results are summarized in table 4.10.

The data suggests that there is a difference (p<.025) in the amount of energy necessary to effect incision of the various food groups. A linear relationship (r=0.828, p<0.02) was found to exist between food dimension and incision BFE values (Figure 4.5).

The data also suggest that there is a difference (p<0.001) in the energy required for the combined tasks of incision and chewing of the various food groups. Again a positive relationship (r=0.921, p<0.005) was found to exist between food dimension and BFE values (Figure 4.5).

For both the phase of incision alone, and the combined phases of incision and chewing there is no statistical suggestion of differences between the AOB and non-AOB groups. Also, there was no indication of a significant interaction between food type and open bite status.

There does appear to be a difference in the pattern of the data between AOB and non-AOB subjects for the task of incision and combined tasks of incision and chewing. These

Table 4.7. Mixed Analysis of Variance Table for the Task of Incision.

| Source of Variation | Degrees of Freedom | Mean Square | F ratio |
|---|---|---|---|
| AOB vs. non-AOB (A) | 1 | 373.53 | 0.058 |
| Within Group | 6 | 6389.42 | |
| Food Type (F) | 3 | 5804.18 | 5.04* |
| F * A Interaction | 3 | 2475.76 | 2.15 |
| Within Food Type | 18 | 1151.29 | |

Significance: *p < 0.025

Table 4.8. Mixed Analysis of Variance for the combined tasks of incision and chewing.

| Source of Variation | Degrees of Freedom | Mean Square | F ratio |
|---|---|---|---|
| AOB vs. non-AOB (A) | 1 | 1.20E+06 | 0.537 |
| Within Group | 6 | 3.72E+06 | |
| Food Type (F) | 3 | 6.21E+06 | 10.77* |
| F * A Interaction | 3 | 4.15E+05 | 0.718 |
| Within Food Type | 18 | 5.77E+05 | |

Significance: *p < 0.001differences are not statistically significant,

Table 4.9. Mixed Analysis of Variance for the energy of incision as a proportion of the energy of the combined tasks of incision and chewing.

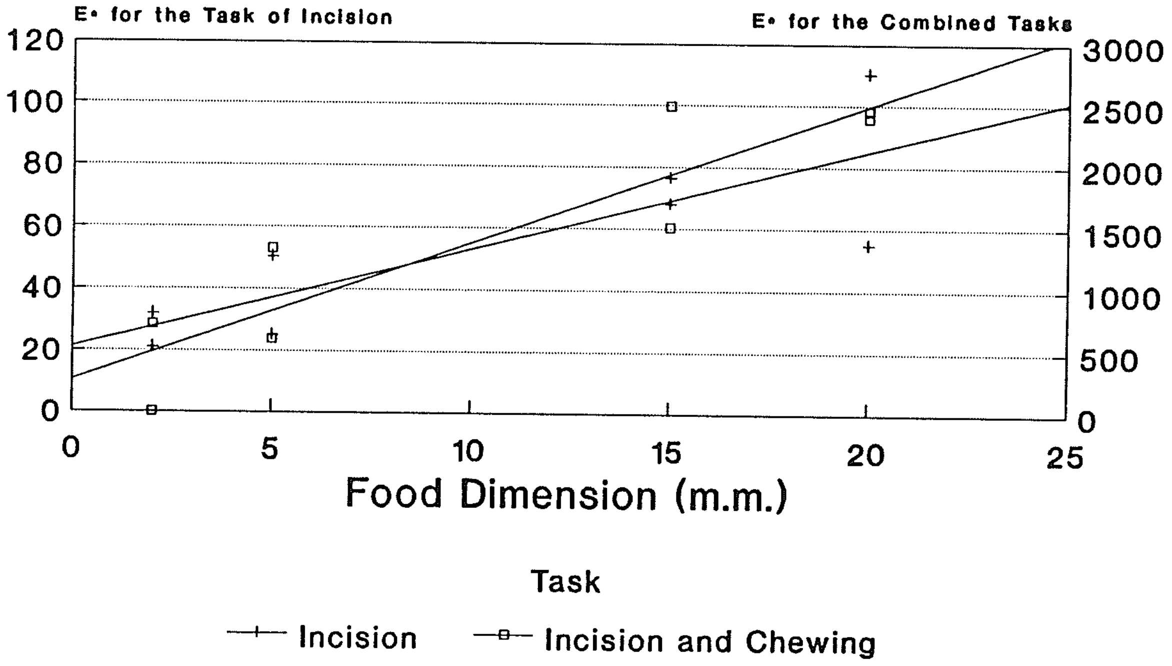
| Source | Degrees of Freedom | Mean Square | F ratio |
|---|---|---|---|
| AOB vs. non-AOB (A) | 1 | 0.0117 | 8.96* |
| Within Group | 6 | 0.0013 | |
| Food Type (F) | 3 | 0.0011 | 1.35 |
| F*A Interaction | 3 | 0.0041 | 4.24* |
| Within Food Type | 18 | 0.0010 | |

Significance
*p < 0.025

Table 4.10. Correlation Coefficients for Covariation Between Food Dimension and Energy (BFE) Values and the Proportion (I/IC) Values.

| Masticatory Task | Subject Group | | |
|---|---|---|---|
| | Combined AOB and non-AOB | non-AOB | AOB |
| Incision (Energy) | $r = 0.828$<br>$p < 0.02$ | $r = 0.991$<br>$p < 0.01$ | $r = 0.741$<br>N.S. |
| Incison and Chewing (Energy) | $r = 0.921$<br>$p < 0.005$ | ------- | ------- |
| Incision as a Proportion of Combined Incision and Chewing. (proportion) | ------- | $r = 0.793$<br>N.S. | $r = -0.998$<br>$p < 0.005$ |

Figure 4.5. Food Dimension vs. Energy For the Task of Incision and the Combined Tasks of Incision and Chewing.



Incision: $r=0.828$, $p<0.02$
Incision and Chewing: $r=0.921$, $p<0.005$
* E is Energy in Bite Force Equivalents

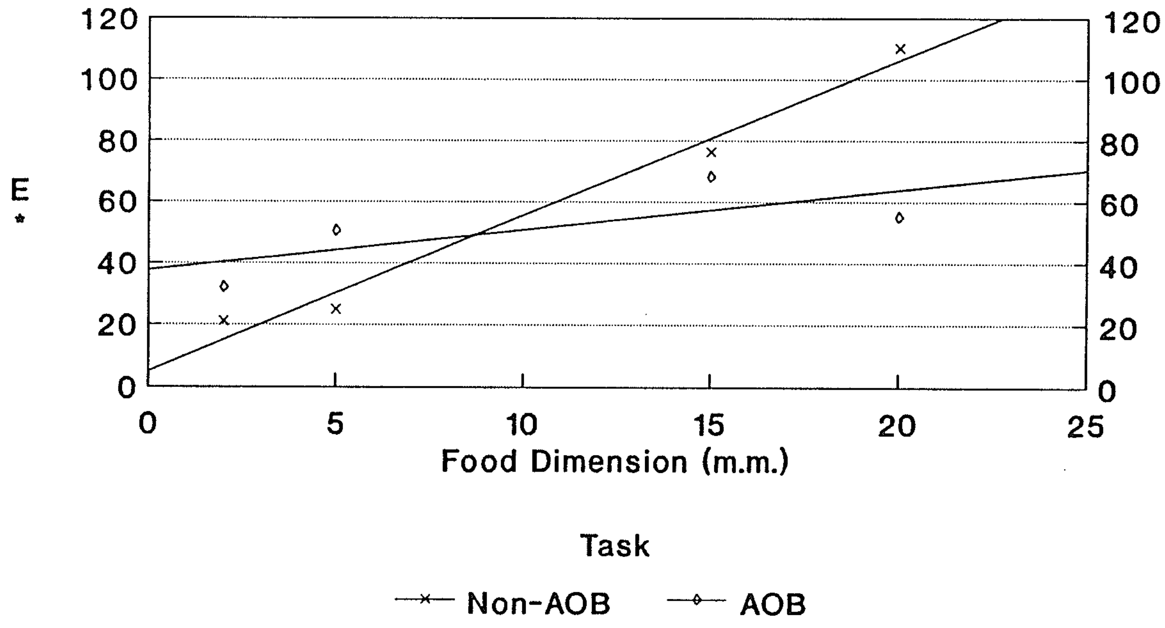
but may be of clinical significance.

For the task of incision alone, the AOB group shows means for all tasks in the range of 32 to 68 BFE. The non-AOB group shows a range of 21 to 110 BFE. It appears that the number of BFE for a smaller dimension food sample is less than one third of the number of BFE required for a larger dimension food sample for the non-AOB group. The AOB group shows smaller dimension food samples requiring greater than 50% of the energy required by the larger dimension food samples.

Figure 4.6 displays the positive relationship which was found to exist in non-AOB subjects between food dimension and the energy required for incision (Table 4.10). However, no significant relationship was found to exist in AOB subjects between food dimension and the energy required for incision (Table 4.10 and Figure 4.6).

In the combined task of incision and chewing, the AOB group uses less than 20% of the BFE for the small versus the large dimension carrot. The non-AOB group uses approximately 33% of the BFE for the small versus the large dimension carrot. Similarly, the AOB group uses less than 40% of BFE for the combined task of incision and chewing for small dimension licorice versus large dimension licorice. The non-AOB group uses greater than 55% of BFE for small dimension versus large dimension licorice samples. These relationships of the patterns from the data on the task of incision alone and the data on the combined tasks of incision and chewing are better

Figure 4.6 Food Dimension vs. Energy For the Task of Incision in Non-AOB and AOB subjects.



Non-AOB: r=0.991, p<0.01
AOB: r=0.741, N.S.
* E is Energy in Bite Force Equivalents

understood by reviewing the I/IC data.

The I/IC data suggest a difference ($p < 0.025$) exists between the AOB and non-AOB groups (Table 4.9.). Also, there is the suggestion of an interactive difference ($p < 0.025$) between the AOB status and the various food groups (Table 4.9). Figure 4.7 displays the weak positive relationship ($r=0.0793$, n.s.) which exists between food dimension and I/IC value in the non-AOB group. However, a significant negative relationship ($r=-0.998$, $p<0.005$) exists between the food dimension and I/IC values for the AOB group (Figure 4.7).

### D. Investigator Error

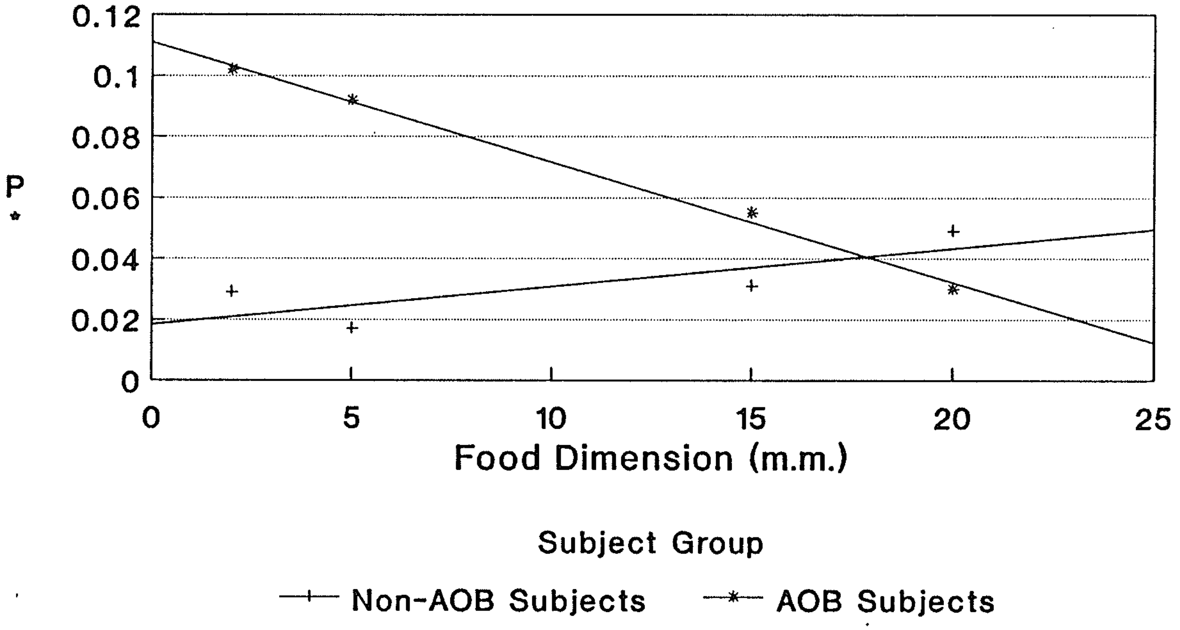
#### 1. Study 1.

The paired quadrant models of subject E.P were mounted, with the mandibular model 2 mm lateral to CO position, on the Houndsfield tensometer on three separate occasions. On each occasion the BFT was placed interocclusally and the five separate force readings were made at the metered resistance level of 2.00 kilo-ohms.

Analysis of variance showed no significant difference in the force measurements made on the three separate occasions (Appendix B). The mean force observed over the three sessions was 25.33 lb. with a standard deviation of 0.79 lb. The standard deviation was found to be 3.11 percent of the mean value.

Thus, investigator error arising from the reproducibility

Figure 4.7.
Relationship of Food Dimension to I/IC Values for Non-AOB and AOB Subjects.



AOB: r=(-)0.998, p<0.005.
NON-AOB: r=0.793, N.S.
* P is Incision/Incision & Chewing Ratio

of mounting the quadrant models on the tensometer for indirect measurement of bite force did not show a great deal of variation.

2. Study 2.

Integrated squared EMG values were calculated for both the task of incision and the combined tasks of incision and chewing, using the microcomputer. On three occasions (separated from each other by at least one week) the masticatory phases were identified five times for each of masticatory trials.

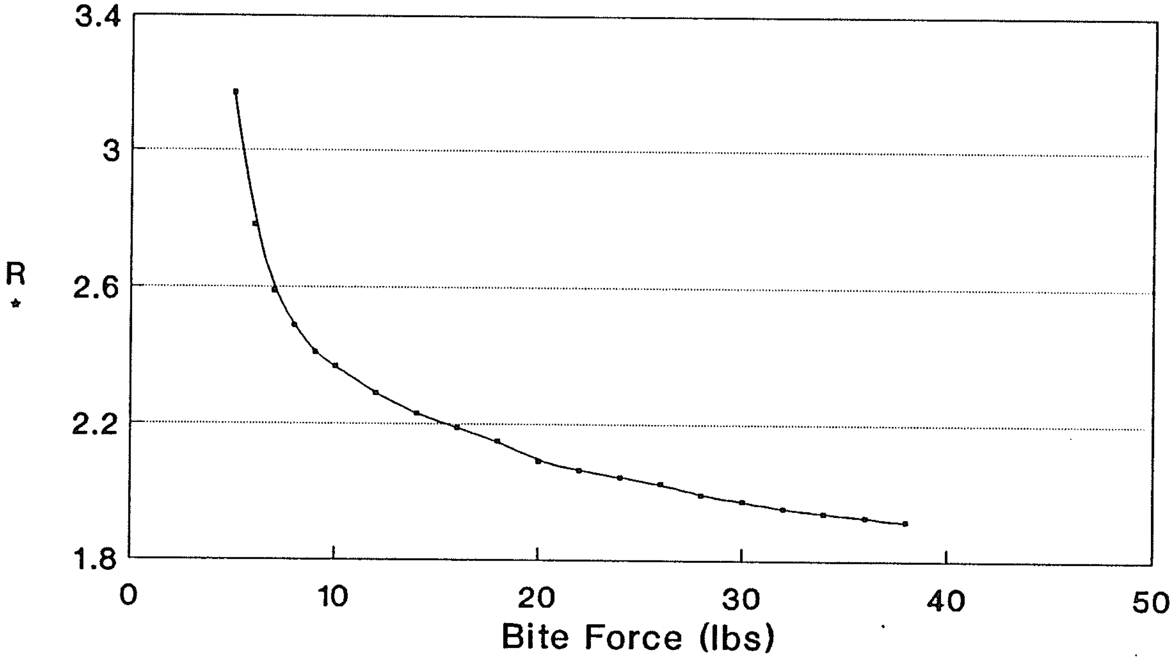
The mean and standard deviation ISq EMG were calculated for each channel (See Appendix C). The standard deviation observed in any channel never exceeded 3.39 percent of the mean value observed.

One can conclude from this study that the investigator error was non-significant as the investigator was consistently able to identify the various phases of the masticatory cycle within a very narrow range of variation.

E) BFT Linearity.

The linear range of the right bite force transducer for patient E.P. was determined to be between 14 and 38 lbs (Figure 4.8). There was a significant positive correlation coefficient between metered resistance readings and bite force found ($r=0.699$, $p<0.01$). One is confident that the bite force transducer responds sufficiently linearly to bite force within the range of 14 to 38 lbs.

Figure 4.8.
Relationship of Bite Force Transducer Resistance to Bite Force.



Linear Range 14-38 lb.
(r=0.699, $p<0.01$)
* R is resistance in kilo-ohms.

As stated in materials and methods, precise linearity of the transducer is not demanded in this study. However, rapid changes in its sensitivity would be undesirable. Figure 4.8 demonstates that no such abrupt changes occur in the working range of the bite force transducer.

# Discussion

"Harmonious functioning of the masticatory system is the general goal toward which dental practice is oriented" (Bates et al., 1975). However, the interdependence of the components of the masticatory apparatus, specifically the teeth and the muscles, may lead one to ask, "Is dental occlusal harmony obligatory for muscle harmony?" (Hannam, 1976). In the present investigation a comparison was made between AOB subjects and non-AOB subjects in order to gain insight into the relationship of anterior dental incompetency and energetic efficiency of the masticatory system. Differences observed between these groups may be an indication that a state of functional disharmony exists in the masticatory apparatus of individuals with AOB malocclusions.

## A. Masticatory Patterns.

The amount of individual subject incision pattern variation as observed from the videorecordings accounts for, in many cases, a great deal of the individual subject variation in the EMG data. There are several factors which may be considered when accounting for this variation. These include: a) the effects of learning on subject behaviour, b) the lack of habituated experience of the subject with specific food types or dimensions; c) over education of experimental subjects who then consciously tried to provide a range of masticatory patterns rather than displaying their natural masticatory patterns and; d) masticatory muscular fatigue.

Learning is a variable which was reduced to some extent in this study by having at least two separate data collection sessions for each subject. This provided the subjects with some familiarity with the recording environment and the masticatory tasks involved. However, the data suggests that for some of the subjects the first trial was different from the subsequent four trials for specific tasks. It may be that the subject must first have some masticatory sensory feedback in order to establish their regular habitual pattern of incision.

Some of the subjects did not appear to be able to establish one specific pattern of incision throughout some specific tasks (i.e. using 3 or 4 different patterns). This may be indicative of the subjects lack of past experience with the sample dimension or sample consistency. Therefore sensory feedback from the first trial was unable to elicit a habitual pattern of incision.

Certain subjects showed cyclic variation in their incision patterns. Often this variation consisted of changing incision and/or chewing from right to left side between trials. This may be a result of the subject intellectualizing the process of experimental research and trying to display a full range of incision patterns, rather than functioning naturally.

The right and left cyclical pattern between trials may also be explained by the phenomenon of muscular fatigue. If the masticatory musculature of a subject was fatigued during any specific trial, the subject may have alternated from right side to left side, or vice versa, on subsequent trials to reduce muscle fatigue and its associated muscle soreness. The subject may have chosen to use a completely different ipsilateral pattern of incision to reduce the masticatory muscle fatigue or masticatory muscle soreness as well. Some of the subjects did complain of muscle soreness during the bite force transducer isometric biting trials, however none complained of muscle soreness during the food trials.

The within subject variation observed was quite large for certain subjects in some groups of trials. The standard deviation was found to be greater than 100% of the mean value over the five trials, in some specific instances. There is some variability expected as a result of limitations of recording equipment, subtle changes in hand position, head position, head posture, and food positioning on the tooth row.

### B. Energetic Efficiency

#### 1. Incision

For the masticatory task of incision alone, differences between food types were observed ($p < 0.025$). These differences may be explained by variation in incision patterns associated with variation in food consistency. Jankelson et al. (1953) described an increase in the retrusive component in the incision pattern as food consistency changed from brittle to soft. This variation in retrusive component of the incisive task may be related to an alteration in energetic efficiency.

Differences may also be explained as a result of variation in food thickness. The results indicate a positive linear relationship between food dimension and energy (ISq EMG) used ($r=0.828$, $p < 0.02$), independent of food consistency.

Manns et al. (1979) found that for a fixed amount of electrical response of the masseter muscle, bite force increases up to a certain range of jaw opening (around 15-20 mm) and then decreases as we approach maximum jaw opening. However, Manns et al. report their electrical response values in mean microvolts, which is a time independent variable.

The present study suggests that to incise a food of increased dimension there is a corresponding increase in energy (ISq EMG) used. Unlike the pattern of the data reported by Manns et al (1979), there does not appear to be an inflection point associated with vertical dimension of opening, up to which the energy output by the musculature increases and after which it decreases. However, the linear relationship observed, between energy and vertical opening, may reflect an increase in the work load of the masticatory apparatus.

For the task of incision alone, differences between non-AOB and AOB groups and differences between food and AOB status interactions were not observed. The pattern of results between AOB and non-AOB groups is interesting, and worthy of further discussion.

Separately, the non-AOB group displayed a significant linear relationship between energy and food dimension (r=0.991, p < 0.01) but, the AOB group displayed no significant relationship (r=0.741, n.s.). It appears that with increased opening, the non-AOB subjects had to overcome an increase in work load with a corresponding increase in masticatory muscle energetic output (Figure 4.6).

The AOB group show a corresponding increase in energy (ISq EMG) from the 2 mm food group through to the 15 mm food group, but then showed a decrease in energy with the 20 mm food sample was observed (Figure 4.6). From the limited sample studied here, one might suspect that the anterior dental incompetency, or some morphological characteristics associated with the AOB deformity has created a work load transition range. The transition range being a vertical dimension of mandibular opening, beyond which one might see a decrease in work load for a given task. This pattern would be similar to the pattern of bite force described by Manns et al. (1979) with an inflection point at a mandibular opening dimension of 15 to 20 mm.

It appears that the AOB and non-AOB groups show a common pattern in their energetic profile for incision of the different food samples. For the AOB group the incision of the smaller diameter foods require greater than 50 % of the energy required for incision of the same consistency but larger diameter food groups. The non-AOB group requires less than 33% of the energy to incise the small diameter food group when compared to the same consistency but larger diameter food group.

These differences again may be explained by this authors overbite dependent transition work load theory. The non-AOB have all their trials within the rising area of their work-load transition curve, thus increased work load with increased in mandibular opening. Therefore the curve is flat when compared to the early part of the AOB group curve (Figure 4.6). The AOB group however, have reached the peak of their work load transition curve at approximately the opening required for incision of the 15 mm food sample. Thus, the curve is very steep before the transition, accounting for the larger values observed for the lower range of mandibular openings in the AOB group. One may hypothesize that mandibular opening which exceeds the work load transition point results in a requirement of less energy rather than more to effect incision.

The non-linear transition observed in the AOB group may be a result of the difference in the consistency of the larger dimension food samples. The licorice perhaps requires a greater masticatory effort because it does not fail from brittle fatigue as easily as the carrot sample, so that longer sustained muscular contractions may be necessary to break the sample.

The data from the present study may be explained more simply as the pattern suggests that proportionately greater amounts of energy are required by the non-AOB subjects in order to incise the larger dimension food samples. This may be directly related to the amount of opening of the mandible necessary to effect incision. Individuals with AOB have a shorter distance of opening in order to enable themselves to incise, and thus may require less energy in order to achieve a bite force adequate to break the food sample.

### 2. Incision and Chewing.

Similar to the task of incision alone, the energy required for the combined tasks of incision and chewing was found to be significantly different between the different food groups ($p < 0.001$). These differences may be the result of individuals incising a greater volume of food from samples of greater cross sectional area. This translates to a greater length of time, or an increase in the number of chewing cycles required to achieve the swallowing threshold. The increase in the number of chewing cycles will require increased energy output from the masticatory musculature.

The above hypothesis is supported by the linear relationship observed for both the AOB and non-AOB groups between the energetic profile and food dimension (r = 0.921, p , 0.005). The energetic profile did not appear to be related to food consistency.

For the combined tasks of incision and chewing there were no significant differences observed between the AOB and non-AOB groups. Also, there was no significant interaction effect between food type and AOB versus non-AOB group. However, the pattern of the data with regard to differences between the subject groups is worthy of discussion.

The AOB group appears to use proportionately less energy than the non-AOB group to incise and chew the various food samples, with the exception of the 20 mm carrot sample which required virtually an identical amount of energy for both of the subject groups. These results may be explained by work of Dahlberg (1942, 1946) and Yurkstas (1965) who report that persons with impaired chewing efficiency appear to compensate for this by swallowing larger particles and not by chewing the food longer or by increasing the rate of chewing. The AOB group have a decrease in the number of tooth contacts, this feature is believed to have a negative effect on masticatory efficiency (Carlsson, 1974, Bates et al., 1976, Gunne, 1985).

Following the above line of reasoning , the present findings are in disagreement with the work of Kawamura and Nobuhara (1957) who found an increase in the length of mastication and the number of chews before swallowing in subjects with malocclusion. One would expect this to translate to an increase rather than a decrease in energy used for the combined tasks of incision and chewing in subjects with AOB. However, of the 22 subjects in the study by Kawamura and Nobuhara (1957), only one had an AOB.

One may hypothesize that for the smaller dimension food samples, the AOB subjects find that following the initial incision, the bolus is much closer in size to that required to meet their swallowing threshold, than that required to meet the swallowing threshold of the non-AOB subjects. Thus the AOB group spends less energy in final food preparation to achieve their "less stringent" swallowing threshold. Because the non-AOB group finds the initial bolus to be much further away in size from that required to meet their swallowing threshold, they spend more energy in order to prepare the food for swallowing.

Continuing with the hypothesis above, the larger dimension samples however are likely to be greatly outside of the range of the swallowing threshold for either group and thus require a specific amount of energy to reduce the bolus to a size suitable for trituration. The crushing phase of mastication may require a common amount of energy in all individuals. Thus the variation observed between groups may be a result of the differences in the amount of energy required in the trituration phase.

Differences observed between the food consistency of the large dimension samples may be indicative of how well the crushing phase is simultaneously involved in trituration. The greater the amount of trituration which occurs concurrently with crushing, the less trituration that will be required at the end of the masticatory cycle for trituration alone.

In the preceding discussion of the combined tasks of incision and chewing up until but not including first swallow, one must not forget that the phase of incision is also contributing to the variation observed.

### 3. Incision as a proportion of combined incision and chewing (I/IC).

The contribution of incision to the combined tasks of incision and chewing is interesting because it is a measurement of each individuals masticatory function. The absolute magnitude of the energy required for the component tasks is no longer a factor, but instead the task of incision is evaluated in terms of the more complex masticatory tasks of incision and chewing. This analysis gives an indication of the cost, in terms of efficiency, to the masticatory cycle of the specific phase (incision) of the masticatory cycle being evaluated.

Previously, it was discussed that the AOB group appeared to have used proportionately more energy than the non-AOB group for incision of small dimension food samples compared to the large food samples. It was also discussed that the AOB group had used less energy than the non-AOB group for the incision and chewing of the food samples. This I/IC analysis combines these two casually observed phenomena and indicates that combined intra-group differences may exist.

The results show that AOB individuals use a significantly greater proportion of their total masticatory cycle energy than non-AOB individuals to effect incision ($p<0.025$). One may conclude that the non-AOB subjects incise more efficiently at a lesser cost to the masticatory apparatus. This phenomenon may be explained in several ways: 1. AOB subjects use the masticatory musculature, as compared to the auxiliary musculature, to a greater extent than non-AOB subjects in order to effect incision; 2. The AOB subjects use the masticatory muscle for greater stabilization of the mandible than the non-AOB subjects during the final phase of food breaking or tearing during incision. Because of their anterior dental incompetency, the AOB subjects are prevented from using their anterior teeth for the same degree of penetration into the food sample in order to break it; 3. The AOB subject may use less energy in the crushing and trituration phases of mastication due to a difference in swallowing threshold (i.e. swallow larger pieces); 4. AOB may be more mechanically efficient than non-AOB in crushing and/or trituration, thus requiring less energy in order to prepare the food for swallowing; 5. The AOB subjects may bite off a smaller volume of food at incision, resulting in lower energy requirement to prepare the food for swallowing. It is likely that a combination of several of these possibilities contribute to the differences reported here.

A significant interaction effect was also observed between subject sample and food sample ($p < 0.025$). Overall there is no significant relationship between I/IC and food sample dimension. It appears that for the AOB subjects, the I/IC increases with an increase in the food sample dimension. Conversely, the non-AOB subjects appear to have a decrease in I/IC with an increase in food sample dimension. The AOB group showed a significant negative linear relationship between I/IC and food dimension ($r=-0.9976$, $p < 0.005$), and the non-AOB group showed a non significant positive linear relationship between I/IC and food dimension ($r=0.793$, n.s.). This may be an indication that the anterior open bite subjects have greater difficulty incising foods of small dimension, which is expected due to the lack of anterior tooth contact. This difficulty with small dimension foods results in a loss in masticatory efficiency, expressed as an increase in cost to the masticatory apparatus.

The non-AOB group values for I/IC were observed within a much narrower range (0.017 to 0.049) than the range of values observed for the AOB group (0.030 to 0.102). The narrow range may be indicative of a common cost to the masticatory system for the phase of incision among non-AOB subjects. The common cost observed may be due to the habitual experience non-AOB individuals have with the various food dimensions sampled. The AOB group displayed a greater range and greater absolute I/IC values in 3 out of the 4 food groups which indicate the greater variability and greater cost of incision to the masticatory system as a result of the dental incompetency. This increase in cost may be due to a lack of habitual experience with the food dimensions sampled.

## C. Clinical Application of the Findings.

The validity of the results of this preliminary study are guarded due to the limited sample size. Differences have been observed in terms of cost to the masticatory system between the AOB and non-AOB subjects. However, the greater cost of incision found in the AOB group will only be of clinical significance if it is beyond the compensatory ability of the masticatory apparatus.

It may be that other genetic or environmental factors, which have not been investigated in this project, contribute at the cellular or biochemical level to alter an individuals ability to repair, to compensate and/or to adapt their masticatory system. This alteration may increase their susceptibility to a breakdown of part of the masticatory apparatus. Once an individual becomes "susceptible", the variations observed in this study may be of clinical significance.

## Conclusions and Recommendations of Further Work

### A. Conclusions

This preliminary investigation was undertaken for the purpose of determining if a reason exists to suspect that there is a cost, in terms of energetic efficiency, to the masticatory apparatus as a result of an anterior dental incompetency. Four anterior open-bite (AOB) subjects and four non anterior open-bite (non-AOB) subjects were used for the purpose of comparing their masticatory energetic profiles during the task of incision, the combined tasks of incision and chewing and for the proportional contribution of incision to the combined tasks of incision and chewing. Foods of varying consistencies and dimensions were used to provide a more complete sample of the masticatory activity range of the subjects. The energetic profile of the masticatory musculature was measured indirectly using ISq EMG, which was then converted to bite force equivalent (BFE) values to allow comparison between subjects. As a result of this work the following conclusions have been made:

1. There is little or no difference between the AOB and non-AOB group in terms of the energy used for the task of incision and for the combined tasks of incision and chewing.
2. The different food samples required significantly different amounts of energy for the task of incision and for the combined tasks of incision and chewing.

3. The energy used for the task of incision, and for the combined tasks of incision and chewing show a positive relationship with the dimension of the food sample.

4. The AOB group and non-AOB group are likely different from each other in the proportional energetic contribution of incision to the combined tasks of incision and chewing (I/IC). This reflects a greater cost to the masticatory apparatus as a result of an AOB malocclusion.

5. The I/IC values appear to display an interaction effect between food sample and overbite status.

6. AOB subjects display a strong negative relationship between food dimension and I/IC values. However, non-AOB subjects display no relationship between food dimension and I/IC values. This reflects a decreased cost to the masticatory system with increased food dimension in individuals with AOB malocclusions.

## B. Suggestions for Future Work

### 1. Reduction in Variability.

There were several sources of variation in this study. Primarily, variation was observed in the within subject and within food sample incision patterns and excessive variation in within subject and within food sample ISq EMG values.

It may be necessary to have the subjects perform specific incision patterns (i.e. the most common patterns observed in the group through pilot trials). This will allow the majority of the subjects to display their habitual patterns during one of the specific pattern trials. This will also allow the investigator to compare different individuals for more identical tasks. Likely once a reduction in variability in incision patterns is achieved the ISq EMG data will be less scattered as well.

2. Further Investigation of Anterior Dental Relationships.

The differences observed, although likely not clinically significant, do pose the question in one's mind: "What is the cost of other forms of anterior dental incompetency to the masticatory apparatus during masticatory function?". One suspects that other static dental relationships displaying anterior dental incompetency associated with excessive overjet and/or overbite may incur a cost to the masticatory apparatus.

Thus, another preliminary investigation, of similar design to this present one, could be considered to determine if the masticatory system must pay a price, in terms of energy, as a result of having an other than "normal" anterior occlusal relationship.

As discussed above, a method to reduce the within-subject variation is necessary for further studies in this area.

3. Further Investigation of Transitional Work Load Theory.

The results from the energy data for the task of incision in the AOB subjects suggests a vertical dimension exists up until which the work load and corresponding energy requirements increase. Beyond this dimension of vertical opening of the mandible the work load begins to decrease again, and this is reflected in a decrease in energy requirements of the masticatory apparatus to effect incision.

Studies of isometric biting at various dimensions indicate that with jaw opening, bite force increases up to a certain range of jaw opening and then decreases as we approach maximum jaw opening (Manns et al., 1979). The transition point is believed to be what has been defined as the muscles resting length. For the masticatory musculature this length is believed to be in the range of 15 to 20 mm from occlusal contact (Manns et al., 1979).

The effect of muscle resting length on muscle work load has not been previously investigated. The data from the AOB group, in this study, during the task of incision suggests a transition in energy output in the range of the so called muscle resting length.

The future investigation could more rigorously control the variables (i.e. one food type, a greater range of jaw opening for incision, a homogeneous sample group, and a homogeneous pattern of incision) involved. However limiting the pattern of incision may limit a true assessment of the subjects' masticatory efficiency, as individual patterns of incision are perhaps a very important component of the overall efficiency of the system. However, this controlled experimental design may contribute to a greater understanding of the effects of muscle resting length on the energy profile of specific masticatory tasks.

# REFERENCES

Ahlgren, J. (1967). An intercutaneous needle electrode for kinesiological EMG studies. Acta Odontol Scand, 25:15-19.

Ahlgren, J. (1966). Mechanism of mastication. Acta Odontol Scand, 24:1-109.

Ahlgren, J. G., Ingervall, B. F., & Thilander, B. L. (1973). Muscle activity in normal and postnormal occlusion. Am J Orthod, 64:445-456.

Ahlgren, J., Sonesson, B., & Blitz, M. (1985). An electromyographic analysis of the temporalis function of normal occlusion. Am J Orthod, 87:230-239.

Angle, E. H. (1899). Classification of malocclusion. Dental Cosmos, 41:248-264.

Arvystas, M. G. (1977). Treatment of anterior skeletal open-bite deformity. Am J Orthod, 72:147-164.

Astrand, P. (1974). Chewing efficiency before and after surgical correction of developmental deformities of the jaws. Swed Dent J, 67:135-146.

Bates, J. R., Stafford, G. D., & Harrison, A. (1975). Masticatory function- A review of the literature. I. The form of the masticatory cycle. J Oral Rehabil, 2: 281-301.

Bates, J. F., Stafford, G. D., & Harrison, A. (1976). Masticatory function- A review of the literature. III. Masticatory performance and efficiency. J Oral Rehabil, 3:57-67.

Bjork, A. (1969). Prediction of mandibular growth rotation. Am J Orthod, 55:585-599.

Budak, A. (1978). Circuit theory fundamentals and applications. Englewood Cliffs, NJ: Prentice Hall.

Cangialosi, T. (1984). Skeletal morphologic features of anterior open bite. Am J Orthod, 85:28-36.

Carlsoo, S. (1952). Nervous coordination and mechanical function of the mandibular elevators. Acta Odontol Scand, 10: Supp. 11:

Carlsson, G. E. (1974). Bite force and chewing efficiency. In: Frontiers in oral physiology. Kawamura, Y. ed. 1. Physiology of mastication:(pp. 265). Basel: Karger.

Carlsson, G. E. (1984). Masticatory efficiency: The effect of age, loss of teeth and prosthetic rehabilitation. Int Dent J, 34:93-97.

Christiansen, E. G. (1924). Note on "Chewing power of teeth". Br Dent J, 45:318.

Dahlberg, B. (1942). The masticatory effect. Acta Med Scand, Suppl. 139:1-156.

Dahlberg, B. (1946). The masticatory habits. J Dent Res, 25:67-72.

Ellis III, E., & McNamara Jr., J. A. (1984). Cephalometric evaluation of incisor position. Angle Orthod, 56:324-44.

Enunla, N. (1974). Palatal and mandibular plane variation in open bite cases with varying etiology. Trans Eur Orthod Soc, 165-171.

Frost, D. E., Fonseca, R. J., Turvey, T. A., & Hall, D. J. (1980). Cephalometric diagnosis and surgical orthodontic correction of apertognathia. Am J Orthod, 78:657-699.

Gunne, J. (1985). Masticatory ability in patients with removable dentures. Swed Dent J, Suppl. 27:

Hannam, A. G. (1976). Is dental occlusal harmony obligatory for muscle harmony? In: Mastication and Swallowing. Sessle, B. J. & Hannam, A. G. eds. Toronto: University of Toronto Press.

Hapak, F. M. (1964). Cephalometric appraisal of the open-bite case. Angle Orthod, 34:65-72.

Helkimo, E., Carlsson, G. E., & Helkimo, M. (1978). Chewing efficiency and state of dentition. Acta Odont Scand, 36:33-41.

Hellman, M. (1931). Open Bite. Am J Orthod Oral Surg, 17: 421-444.

Hovell, J. H. (1968). Aetiology and development of open bite. In: 3rd International conference on Oral Surgery. R.V. Walker (ed.) (pp. 2-7). New York: Livingstone.

Issacson, J. R., Issacson, R. J., Speidel, T. M., & Worms, F. W. (1971). Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. Angle Orthod, 41:219-229.

Jankelson, B., Hoffman, G. M., & Hendron, J. A. (1953). Physiology of the stomatognathic system. J Am Dent Assoc, 46:375-386.

Jarabak, J. R. (1983). Open bite: Skeletal morphology. Fortschr Kieferorthop, 44:122-133.

Kawamura, Y., & Nobuhara, M. (1957). Studies on masticatory function. II. The swallowing threshold of persons with normal occlusion and malocclusion. Med J Osaka Univ, 8:241-246.

Kim, Y. H. (1974). Overbite depth indicator with particular reference to anterior open-bite. Am J Orthod, 65:586-611.

Kwon, H. J., Bevis, R. R., & Waite, D. E. (1984). Apertognathia (open bite) and its surgical management. Int J Oral Surg, 13:278-289.

Kydd, W. L., Akamine, J. S., Mendel, R. A., & Kraus, B. S. (1963). Tongue and lip forces exerted during deglutition in subjects with and without an anterior open bite. J Dent Res, 42:858-866.

Latif, A. (1957). An electromyographic study of the temporalis muscle in normal persons during selected positions and movements of the mandible. Am J Orthod, 43:577-591.

Lehr Jr., R. P., & Owens Jr., S. E. (1980). An electromyographic study of human lateral pterygoid muscles. Anat Rec, 196:441-448.

Linder-Aronson, S. (1970). Adenoids: Their effect on mode of breathing and nasal air flow and their relationship to characteristics of the facial skeleton and dentition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryng, Suppl 265:1+.

Linder-Aronson, S. (1975). Effects of adenoidectomy on the dentition and facial skeleton over a period of five years. In: Transactions of the third international orthodontic congress. Cook, J. T. ed. (pp. 85-100). St. Louis: C.V. Mosby Co.

Loos, S. (1963). A simple test of masticatory function. Int Dent J, 13:615-616.

Loufty, M. S. (1973). Cephalometric evaluation of deep overbite and anterior open bite in Kuwait school children. Trans Europ Orthod Soc, 281-285.

Lowe, A. A. (1980). Correlation between orofacial muscle activity and craniofacial morphology in a sample of control and anterior open bite subjects. Am J Orthod, 78:89-98.

Lowe, A. A., Gurza, S. C., & Sessle, B. J. (1977). Regulation of genioglossus and masseter muscle activity in man. Arch Oral Biol, 22:579-584.

Lowe, A. A., Takada, K., & Taylor, L. M. (1983). Muscle activity during function and its correlation with craniofacial morphology in a sample of subjects with Class II, Division 1 malocclusions. Am J Orthod, 84: 204-211.

MacDougall, J. D. B, & Andrew, B. L. (1953). An electromyographic study of the temporalis and masseter muscles. J Anat, 87:37-45.

Manly, R. S. (1951). Factors affecting masticatory performance and efficiency among young adults. J Dent Res, 30:874-882.

Manly, R. S., & Braley, L. C. (1950). Masticatory performance and efficiency. J Dent Res, 29:449-462.

Manns, A., Miralles, R., & Palazzi, C. (1979). EMG, bite force, and elongation of the masseter muscle under isometric voluntary contractions and variations in vertical dimension. J Prosthet Dent, 42:674-682.

McCollum, B. B. (1943). Oral Diagnosis. J Am Dent Assoc, 30:1218-1233.

Moller, E. (1966). The chewing apparatus. Acta Physiol Scand, 69: suppl. 280:1-229.

Moyers, R. E. (1950). An electromyographic analysis of certain muscles involved in temporomandibular movement. Am J Orthod, 36:481-515.

Moyers, R. E. (1963). Handbook of orthodontics, ed. 2. Chicago: Year Book Medical Publishers, Inc.

Moyers, R. E. (1949). Temporomandibular muscle contraction patterns in Angle Class II Division 1 malocclusions: An electromyographic analysis. Am J Orthod, 35:837-857.

Muller, G. (1963). Growth and development of the middle face. J Dent Res, 42:385-399.

Nagasawa, T., & Tsuru, H. (1973). A comparative evaluation of masticatory efficiency of fixed and removable restorations replacing mandibular first molars. J Prosthet Dent, 30:263-273.

Nahoum, H. I. (1975). Anterior open-bite: A cephalometric analysis and suggested treatment procedures. Am J Orthod, 67:513-521.

Nahoum, H. I. (1971). Vertical proportions and the palatal plane in anterior open-bite. Am J Orthod, 59:273-282.

Nahoum, H. I., Horowitz, S. L., & Benedicto, E. A. (1972). Varieties of anterior open-bite. Am J Orthod, 61:486-492.

Neff, C. W., & Kydd, W. L. (1966). The open bite: Physiology and occlusion. Angle Orthod, 36:351-357.

Proffit, W. R., & Bell, W. H. (1980). Surgical correction of dentofacial deformities. Philadelphia: WB Saunders Co.

Proffit, W. R., Chastain, B. B., & Norton, L. A. (1969). Linguopalatal pressure in children. Am J Orthod, 55: 154-166.

Pruzansky, S. (1952). The application of electromyography to dental research. J Am Dent Assoc, 44:49-68.

Pruzansky, S. (1958). Quantitative electromyographic analysis of mastication. Am J Orthod, 44:307.

Ralston, H. J. (1961). Uses and limitations of electromyogram in the quantitative skeletal muscle function. Am J Orthod, 47:521-530.

Ramfjord, S., & Ash, M. M. (1983). Occlusion, 3rd Edition. Philadelphia: W.B. Saundrs Co.

Richardson, A. (1969). Skeletal factors in anterior open-bite and deep overbite. Am J Orthod, 56:114-127.

Roehm, E. G. (1981). Computed tomographic measurement of tongue volume relative to its surrounding space. M.Sc. Thesis. : University of Manitoba.

Sassouni, V. (1969). A classification of skeletal facial types. Am J Orthod, 55:109-123.

Sassouni, V., & Nanda, S. (1964). Analysis of dentofacial vertical proportions. Am J Orthod, 50:801-823.

Schendel, S. A., Eisenfeld, J., Bell, W. H., Epker, B. N., & Mishelevich, D. J. (1976). The long face syndrome: Vertical maxillary excess. Am J Orthod, 70:398-408.

Schudy, F. F. (1964). Vertical growth versus anteroposterior growth as related to function and treatment. Angle Orthod, 34:75-93.

Shira, R. B. (1961). Surgical correction of open bite deformities by oblique sliding osteotomy. J Oral Surg Anaes Hosp Dent Serv, 19:275-290.

Shira, R. B., & Alling, C. C. (1970). Mandibular surgery for the correction of open bite. Trans Congr Int Assoc Oral Surg, 37-59.

Simon, P. W. (1924). On gnathostatic diagnosis in orthodontics. Int J Orthod Oral Surg Radiol, 10:755-777.

Straub, W. B. (1960). Malfunctions of the tongue. Part 1. The abnormal swallowing habit: its cause, effects and results in relation to orthodontic treatment and speech therapy. Am J Orthod, 46:404-424.

Subtelny, J. D., & Sakuda, M. (1964). Open-bite: diagnosis and treatment. Am J Orthod, 50:337-358.

Subtelny, J. D., & Subtelny, J. D. (1973). Oral habits -- Studies in form, function and therapy. Angle Orthod, 43:349-383.

Swinehart, E. W. (1942). A clinical study of open-bite. Am J Orthod, 28:18-34.

Thoma, K. H. (1969). Oral Surgery, 5th Edition. St Louis: CV Mosby Co.

Trouten, J. C., Enlow, D. H., Rabine, M., Phelps, A. E., & Swedlow, D. (1983). Morphologic factors in open bite and deep bite. Angle Orthod, 53:192-211.

Tzakis, M. G., Kiliaridis, S., & Carlsson, G. E. (1989). Effects of chewing training on masticatory efficiency. Acta Odont Scand, 47:355-360.

Vitti, M. (1971). Electromyographic analysis of the musculus temporalis in basic movements of the jaw. Electromyography, 11:389-403.

Vitti, M., & Basmajian, J. V. (1977). Integrated actions of the masticatory muscles: Silmutaneous EMG from eight intramuscular electrodes. Anat Rec, 187:173-189.

Vitti, M., & Basmajian, J. V. (1975). Muscles of mastication in small children. An electromyographic analysis. Am J Orthod, 68:412-418.

Warren, J. (1966). Quantitative aspects of blood flow and oxygen uptake in human forearn during rhythmic exercise. Acta Physiol Scand, 67: Suppl. 269:1-93.

Woelfel, J. B., Hickey, J. C., Stacy, R. W., & Rinear, B. A. (1960). Electromyograpic analysis of jaw movements. J Prosthet Dent, 10:688-697.

Worms, F. W., Meskin, L. H., & Issacson, R. J. (1971). Open-bite. Am J Orthod, 59:589-595.

Yurkstas, A. A. (1965). The masticatory act. J Prosthet Dent, 15:248-262.

Yurkstas, A. A., & Manly, R. S. (1949). Measurement of occlusal contact area effective in mastication. Am J Orthod, 35:185-196.

# APPENDIX I.

# Information Sheet for Prospective Subjects

## A Study of the Efficiency of Chewing in Humans

The purpose of this research is to improve our understanding of the design and function of the human chewing apparatus by increasing our knowledge about its efficiency in biting and chewing. The principle investigator has qualifications as a general dentist and is conducting this research in fulfilment of his M.Sc. degree, and specialty certification in orthodontics.

The basic research techniques involved in this study are used commonly as a part of dental examination, and/or in clinical research involving human subjects. These techniques are non-invasive, and are not associated with any known harm or irreversible changes to human tissue or organ systems.

Subjects for this biting study will be required to have electrical activity (EMG) from two pairs of jaw muscles recorded while performing a number of simple biting tasks. These tasks will involve biting a variety of food stuffs. The scrubbing and cleaning of the skin of the cheeks and sides of the forehead (using rubbing alcohol) will be required, in preparation for the application of small monitors to these areas.

The general health and well being of the subjects participating should not be affected by any of the techniques applied in this study. Furthermore, immediate and obvious physical benefits to the participants as a result of this study are not expected. On the other hand, significant foreseeable risks to the subject are highly unlikely. Among the remote, but possible risks are: allergic reaction to the material used; accidental swallowing or inhaling of experimental materials; tenderness and/or redness in the area of the skin prepared for the recording electrodes; minor discomfort during adhesive tape removal from the skin; slight jaw muscle tiredness for a short time following the experiments. Risks of damage to the teeth and jaws should be no greater that the risks involved in the biting and chewing of ordinary foods.

The time commitment required is approximately three, one and one half hour sessions. A short time will be spent to discuss the experimental protocol, to obtain consent, and to briefly review the subject's dental and medical history. The muscle recordings (EMG) will then be carried out. The subject will be asked to: shave (men only) or wash the face, brush the teeth, and avoid applying any facial ointments or make up before arriving for the recording session.

Subjects should contact Dr. Sherman at or , should any questions, or problems arise regarding this study.

## University of Manitoba - Faculty of Graduate Studies

## Biting Study: Consent Form

I have agreed to participate in a study of chewing function to be conducted by Michael W. Sherman, Graduate Student, Preventive Dental Science/Graduate Studies M.Sc. Program. I have read the information sheet about the study, and it has also been explained to me by Dr. Sherman. I understand that the study will require the making of some standard dental records and will involve surface electromyographic (EMG) recordings from four jaw muscles during some biting and chewing tasks employing ordinary foodstuffs. These biting and chewing tasks are not expected to demand any extraordinary effort of the chewing apparatus.

I understand that there are no specific, personal benefits to be realized as a result of my participation in this study, but that the results of the research are expected to contribute to scientific knowledge and to future clinical treatment in dentistry. I understand that the risks of personal harm or discomfort involved with this study are very small. It has been explained that although the possibilities are remote, should any problems associated with my participation in this study occur and persist, I will be seen for advice and/or treatment as appropriate in the University of Manitoba Orthodontic Clinic.

I consent to having the following records of me made; with the understanding that they will become property of the University of Manitoba, and will be held in confidence, but may be used for research publication and presentation purposes:

1. History and examination records.
2. Impressions for dental models.
3. Bite registration records.
4. Side view, frontal view head and shoulder photographs and videorecordings.
5. Surface electromyography.

I have volunteered to participate in this study on my own accord, and I realize that I am free to withdraw from participation at any time without penalty.

Name of Subject (please print):________________________________.

Signature of Subject:____________________________________________.

Date:________________________________________.

Signature of Witness________________________.

# University of Manitoba - Faculty of Graduate Studies

## Biting Study: Medical-Dental History Form

Name: ______________________________ Date: ____________

Address: ____________________________________________

Telephone No.: (Home) ______________ (Work) ______________

Birthdate (Day-Month-Year): ____________ Present Age: ________

### Medical History

Physician's Name: __________________________

| | Yes | No |
|---|---|---|
| Currently under a physician's care? | ___ | ___ |
| Currently taking any medication? | ___ | ___ |
| Currently under psychological guidance? | ___ | ___ |
| Past Severe Illnesses? | ___ | ___ |
| Past Operations and/or hospitalizations? | ___ | ___ |
| Birth defects? | ___ | ___ |
| Past or current allergies? | ___ | ___ |

Please explain all "Yes" answers:

____________________________________________________________

____________________________________________________________

____________________________________________________________

______________

### Dental History

Dentist's Name: ______________________________

How often do you visit your dentist? ____________

When was your last dental appointment? ____________

| | Yes | No |
|---|---|---|
| Are you presently undergoing dental treatment? | ___ | ___ |
| Have you ever had orthodontic treatment? | ___ | ___ |
| Did you ever or do you: | | |
| Clench or grind your teeth? | ___ | ___ |
| Have difficulty chewing or swallowing? | ___ | ___ |
| Have problems with your jaws, jaw joints or jaw muscles? | ___ | ___ |

Please explain all "Yes" answers:

____________________________________________________________

____________________________________________________________

____________________________________________________________

______________

# Appendix II

## Supplementary Study 1.

This study involved mounting quadrant models with the indexed BFT on the Houndsfield tensometer, and making repeated force measurements (See methods and materials for further details).

The following is a summary of the data collected from the three sessions. Also, the summary table from the analysis of variance is presented.

Table II.1 Supplementary Study 1: Summary of Data

| Session | Mean Force (lb) | Overall Mean | Overall S.D.* | S.D./Mean |
|---|---|---|---|---|
| 1 | 26.1 | 25.33 | 0.789 | 0.031 |
| 2 | 24.6 | | | |
| 3 | 25.3 | | | |

* S.D. = standard deviation

Table II.2 Supplementary Study 1: Analysis of Variance

| Source of Variance | Sums of Squares | Degrees of Freedom | Mean Square | F Value |
|---|---|---|---|---|
| Between Session | 5.63 | 2 | 2.82 | 0.004* |
| Within Session | 9636 | 12 | 803 | |
| Total | 9641.63 | 14 | | |

* N.S.

# Appendix III

## Supplementary Study II.

This study involved evaluating the repeatability of the identification of the various masticatory phases from the EMG and videotape recordings. For further details please refer to the methods and materials section (Chapter 3).

The following is a summary of the results of this study. Means and standard deviations (S.D.) are reported in volts squared-seconds (ISq values).

Each trial was designated with a specific code which appears below. The first two letters are the subjects initials, the digit following these is the session number. The letter and number combination following the first three letters represents the food type and dimension (i.e. C20 indicates 20 mm carrot). The final letter represents the trial, a indicating first trial through e the fifth trial.

Trial: MC2C20C
Task: Incision

| Muscle | Mean(M) | S.D.(SD) | SD/M*100% |
|---|---|---|---|
| Right Masseter | 9.49E+06 | 3.40E+04 | 0.36% |
| Left Masseter | 1.30E+07 | 0.00E+00 | 0.00% |
| Right Ant. Temporalis | 4.37E+05 | 1.48E+04 | 3.39% |
| Left Ant. Temporalis | 3.40E+06 | 0.00E+00 | 0.00% |

Trial: MC2C20C
Task: Incision and Chewing

| Muscle | Mean(M) | S.D.(SD) | SD/M*100% |
|---|---|---|---|
| Right Masseter | 3.50E+08 | 0.00E+00 | 0.00% |
| Left Masseter | 5.30E+08 | 0.00E+00 | 0.00% |
| Right Ant. Temporalis | 1.30E+08 | 0.00E+00 | 0.00% |
| Left Ant. Temporalis | 2.70E+08 | 0.00E+00 | 0.00% |

Trial: TS3C2C
Task: Incision

| Muscle | Mean(M) | S.D.(SD) | SD/M*100% |
|---|---|---|---|
| Right Masseter | 2.85E+06 | 4.99E+04 | 1.75% |
| Left Masseter | 1.10E+08 | 0.00E+00 | 0.00% |
| Right Ant. Temporalis | 2.00E+07 | 0.00E+00 | 0.00% |
| Left Ant. Temporalis | 1.43E+06 | 4.42E+04 | 3.10% |

Trial: MC2C20C
Task: Incision and Chewing

| Muscle | Mean(M) | S.D.(SD) | SD/M*100% |
|---|---|---|---|
| Right Masseter | 1.70E+08 | 0.00E+00 | 0.00% |
| Left Masseter | 3.83E+08 | 6.80E+06 | 1.78% |
| Right Ant. Temporalis | 1.30E+08 | 0.00E+00 | 0.00% |
| Left Ant. Temporalis | 5.81E+07 | 3.40E+05 | 0.59% |

# Appendix IV

## Subject Data

The following pages contain the EMG bite force equivalent data for each of the subjects. Values reported for the task of incision and the combined tasks of incision and chewing (I&C*) are in bite force equivalent units which were calculated from the ISq values in the manner described in the materials and methods section (Chapter 3.) Proportional values in the column labelled (Incision/I&C) were calculated by dividing the BFE values for the task of incision by the BFE values for the combined tasks of incision and chewing.

Trials are listed in the left hand column. The first letter indicates the food type (c=carrot and l=licorice), the number following indicates the food dimension (2=2 mm, 5 =5 mm, 15=15 mm and 20=20 mm). The final letter indicates the trial. Summary statistics are presented at the bottom of each page. The tasks are indicated in the left hand column, using the same abbreviations as above (no trials).

All values were obtained from the final EMG and video recording session for each subject. AOB subjects were each seen for three recording session and non-AOB subjects were each seen for two recording sessions.

Subject M.C.

Bite force equivalents

|  | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 17.47 | 809.04 | 0.022 |
| C2B | 75.47 | 1697.15 | 0.044 |
| C2C | 23.65 | 1367.37 | 0.017 |
| C2D | 13.20 | 1436.23 | 0.009 |
| C2E | 8.64 | 1743.34 | 0.005 |
| C20A | 50.53 | 4565.95 | 0.011 |
| C20B | 31.45 | 3561.67 | 0.009 |
| C20C | 59.68 | 3794.68 | 0.016 |
| C20D | 97.40 | 3614.56 | 0.027 |
| C20E | 54.26 | 2786.41 | 0.019 |
| L5A | 21.98 | 1906.07 | 0.012 |
| L5B | 35.31 | 1532.49 | 0.023 |
| L5C | 24.27 | 2157.57 | 0.011 |
| L5D | 23.71 | 1992.24 | 0.012 |
| L5E | 17.34 | 1604.00 | 0.011 |
| L15A | 75.60 | 3629.33 | 0.021 |
| L15B | 62.52 | 3745.11 | 0.017 |
| L15C | 63.84 | 4069.69 | 0.016 |
| L15D | 57.16 | 3914.24 | 0.015 |
| L15E | 56.71 | 4673.90 | 0.012 |
| Mean |  |  |  |
| C2 | 27.688 | 1410.627 | 0.020 |
| C20 | 58.665 | 3664.654 | 0.016 |
| L5 | 24.522 | 1838.475 | 0.014 |
| L15 | 63.169 | 4006.453 | 0.016 |
| Standard Deviation |  |  |  |
| C2 | 24.40 | 333.83 | 0.014 |
| C20 | 21.58 | 568.10 | 0.006 |
| L5 | 5.92 | 236.07 | 0.005 |
| L15 | 6.83 | 365.65 | 0.003 |

* I&C is Incision and Chewing

Subject G.H.

Bite force equivalents

| | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 1.42 | 323.89 | 0.004 |
| C2B | 1.22 | 203.90 | 0.006 |
| C2C | 3.47 | 414.00 | 0.008 |
| C2D | 10.30 | 157.65 | 0.065 |
| C2E | 1.73 | 317.68 | 0.005 |
| C20A | 35.11 | 1808.25 | 0.019 |
| C20B | 45.48 | 2040.97 | 0.022 |
| C20C | 36.81 | 1168.57 | 0.032 |
| C20D | 26.69 | 1699.01 | 0.016 |
| C20E | 34.65 | 1537.33 | 0.023 |
| L5A | 3.20 | 496.62 | 0.006 |
| L5B | 3.70 | 565.49 | 0.007 |
| L5C | 2.49 | 552.88 | 0.005 |
| L5D | 2.51 | 604.94 | 0.004 |
| L5E | 1.89 | 729.35 | 0.003 |
| L15A | 33.18 | 2662.22 | 0.012 |
| L15B | 30.85 | 1766.12 | 0.017 |
| L15C | 18.78 | 1857.98 | 0.010 |
| L15D | 22.92 | 1303.80 | 0.018 |
| L15E | 32.39 | 1845.28 | 0.018 |
| Mean | | | |
| C2 | 3.627 | 283.421 | 0.018 |
| C20 | 35.749 | 1650.824 | 0.022 |
| L5 | 2.759 | 589.855 | 0.005 |
| L15 | 27.626 | 1687.080 | 0.015 |
| Standard Deviation | | | |
| C2 | 3.43 | 91.66 | 0.024 |
| C20 | 5.99 | 291.47 | 0.005 |
| L5 | 0.63 | 77.90 | 0.001 |
| L15 | 5.73 | 437.79 | 0.003 |

* I&C is Incision and Chewing

Subject R.K.

Bite force equivalents

|  | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 7.40 | 296.90 | 0.025 |
| C2B | 5.46 | 300.29 | 0.018 |
| C2C | 6.71 | 288.20 | 0.023 |
| C2D | 6.32 | 295.58 | 0.021 |
| C2E | 4.82 | 324.49 | 0.015 |
| C20A | 37.88 | 1696.87 | 0.022 |
| C20B | 103.96 | 911.79 | 0.114 |
| C20C | 57.10 | 1479.88 | 0.039 |
| C20D | 119.41 | 1149.78 | 0.104 |
| C20E | 71.73 | 1178.87 | 0.061 |
| L5A | 22.71 | 803.48 | 0.028 |
| L5B | 9.61 | 800.81 | 0.012 |
| L5C | 12.79 | 625.24 | 0.020 |
| L5D | 11.14 | 675.16 | 0.016 |
| L5E | 14.44 | 624.77 | 0.023 |
| L15A | 66.02 | 1941.35 | 0.034 |
| L15B | 59.24 | 1686.28 | 0.035 |
| L15C | 50.39 | 1318.63 | 0.038 |
| L15D | 41.05 | 1136.80 | 0.036 |
| L15E | 48.40 | 1286.24 | 0.038 |
|  |  |  |  |
| Mean |  |  |  |
| C2 | 6.142 | 301.093 | 0.021 |
| C20 | 78.018 | 1283.438 | 0.068 |
| L5 | 14.136 | 705.891 | 0.020 |
| L15 | 53.024 | 1473.856 | 0.036 |
| Standard Deviation |  |  |  |
| C2 | 0.91 | 12.35 | 0.004 |
| C20 | 29.92 | 274.38 | 0.036 |
| L5 | 4.58 | 80.70 | 0.006 |
| L15 | 8.71 | 295.49 | 0.002 |

* I&C is Incision and Chewing

Subject E.P.

Bite force equivalents

| | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 101.46 | 933.73 | 0.109 |
| C2B | 29.06 | 894.88 | 0.032 |
| C2C | 32.04 | 525.16 | 0.061 |
| C2D | 24.10 | 871.87 | 0.028 |
| C2E | 45.54 | 890.40 | 0.051 |
| C20A | 334.96 | 3777.03 | 0.089 |
| C20B | 356.53 | 3451.07 | 0.103 |
| C20C | 260.99 | 2575.15 | 0.101 |
| C20D | 211.93 | 2465.28 | 0.086 |
| C20E | 179.21 | 2645.81 | 0.068 |
| L5A | 36.78 | 2422.82 | 0.015 |
| L5B | 55.11 | 2410.26 | 0.023 |
| L5C | 59.00 | 1664.68 | 0.035 |
| L5D | 56.51 | 2187.31 | 0.026 |
| L5E | 83.16 | 2103.17 | 0.040 |
| L15A | 224.15 | 2546.86 | 0.088 |
| L15B | 247.15 | 2832.04 | 0.087 |
| L15C | 97.67 | 2560.70 | 0.038 |
| L15D | 119.22 | 2888.36 | 0.041 |
| L15E | 119.86 | 2155.76 | 0.056 |
| Mean | | | |
| C2 | 46.441 | 823.209 | 0.056 |
| C20 | 268.725 | 2982.868 | 0.089 |
| L5 | 58.112 | 2157.688 | 0.028 |
| L15 | 161.612 | 2596.743 | 0.062 |
| Standard Deviation | | | |
| C2 | 28.41 | 150.38 | 0.029 |
| C20 | 68.41 | 528.71 | 0.013 |
| L5 | 14.80 | 275.97 | 0.009 |
| L15 | 61.41 | 260.26 | 0.022 |

* I&C is Incision and Chewing

Subject L.M.

Bite force equivalents

| | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 34.97 | 375.27 | 0.093 |
| C2B | 16.18 | 334.50 | 0.048 |
| C2C | 13.44 | 215.65 | 0.062 |
| C2D | 10.33 | 204.01 | 0.051 |
| C2E | 13.50 | 214.62 | 0.063 |
| C20A | 58.05 | 1382.97 | 0.042 |
| C20B | 35.89 | 1898.94 | 0.019 |
| C20C | 33.89 | 1524.55 | 0.022 |
| C20D | 35.94 | 1364.01 | 0.026 |
| C20E | 75.57 | 1455.15 | 0.052 |
| L5A | 75.99 | 607.56 | 0.125 |
| L5B | 49.08 | 410.21 | 0.120 |
| L5C | 54.85 | 435.99 | 0.126 |
| L5D | 51.09 | 399.18 | 0.128 |
| L5E | 31.52 | 399.57 | 0.079 |
| L15A | 123.63 | 981.52 | 0.126 |
| L15B | 76.07 | 973.12 | 0.078 |
| L15C | 36.03 | 743.85 | 0.048 |
| L15D | 42.84 | 664.37 | 0.064 |
| L15E | 48.99 | 708.44 | 0.069 |
| | | | |
| Mean | | | |
| C2 | 17.683 | 268.810 | 0.063 |
| C20 | 47.869 | 1525.123 | 0.032 |
| L5 | 52.505 | 450.502 | 0.115 |
| L15 | 65.512 | 814.262 | 0.077 |
| Standard Deviation | | | |
| C2 | 8.84 | 71.57 | 0.016 |
| C20 | 16.45 | 195.35 | 0.013 |
| L5 | 14.22 | 79.66 | 0.018 |
| L15 | 32.08 | 135.53 | 0.026 |

* I&C is Incision and Chewing

Subject P.S.

Bite force equivalents

| | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 21.93 | 514.11 | 0.043 |
| C2B | 10.57 | 532.93 | 0.020 |
| C2C | 35.40 | 267.68 | 0.132 |
| C2D | 39.64 | 769.92 | 0.051 |
| C2E | 60.80 | 598.34 | 0.102 |
| C20A | 83.28 | 5485.89 | 0.015 |
| C20B | 69.85 | 5040.68 | 0.014 |
| C20C | 130.45 | 6186.64 | 0.021 |
| C20D | 118.97 | 7051.01 | 0.017 |
| C20E | 68.13 | 6022.67 | 0.011 |
| L5A | 112.81 | 1436.93 | 0.079 |
| L5B | 116.96 | 1691.83 | 0.069 |
| L5C | 75.61 | 1074.18 | 0.070 |
| L5D | 70.17 | 1515.54 | 0.046 |
| L5E | 83.48 | 948.42 | 0.088 |
| L15A | 119.92 | 4057.50 | 0.030 |
| L15B | 179.73 | 3036.86 | 0.059 |
| L15C | 110.76 | 4694.02 | 0.024 |
| L15D | 135.53 | 3236.25 | 0.042 |
| L15E | 60.08 | 2237.51 | 0.027 |
| Mean | | | |
| C2 | 33.668 | 536.596 | 0.070 |
| C20 | 94.137 | 5957.419 | 0.016 |
| L5 | 91.807 | 1333.382 | 0.070 |
| L15 | 121.205 | 3452.426 | 0.036 |
| Standard Deviation | | | |
| C2 | 17.01 | 161.92 | 0.041 |
| C20 | 25.76 | 680.46 | 0.003 |
| L5 | 19.36 | 278.49 | 0.014 |
| L15 | 38.67 | 848.90 | 0.013 |

* I&C is Incision and Chewing

Subject T.S.

Bite force equivalents

| | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 5.50 | 218.93 | 0.025 |
| C2B | 16.33 | 266.33 | 0.061 |
| C2C | 20.86 | 223.56 | 0.093 |
| C2D | 29.44 | 217.45 | 0.135 |
| C2E | 32.07 | 306.33 | 0.105 |
| C20A | 14.13 | 1098.94 | 0.013 |
| C20B | 41.90 | 1115.38 | 0.038 |
| C20C | 26.78 | 588.23 | 0.046 |
| C20D | 21.80 | 1470.65 | 0.015 |
| C20E | 21.24 | 1771.74 | 0.012 |
| L5A | 34.43 | 277.67 | 0.124 |
| L5B | 69.03 | 338.21 | 0.204 |
| L5C | 47.21 | 328.93 | 0.144 |
| L5D | 50.53 | 300.63 | 0.168 |
| L5E | 37.56 | 494.91 | 0.076 |
| L15A | 42.37 | 1327.27 | 0.032 |
| L15B | 27.19 | 977.35 | 0.028 |
| L15C | 180.10 | 963.93 | 0.187 |
| L15D | 22.15 | 1001.13 | 0.022 |
| L15E | 21.61 | 1729.78 | 0.012 |
| Mean | | | |
| C2 | 20.841 | 246.521 | 0.084 |
| C20 | 25.168 | 1208.988 | 0.025 |
| L5 | 47.752 | 348.071 | 0.143 |
| L15 | 58.686 | 1199.892 | 0.056 |
| Standard Deviation | | | |
| C2 | 9.55 | 34.94 | 0.038 |
| C20 | 9.28 | 397.84 | 0.014 |
| L5 | 12.18 | 76.46 | 0.043 |
| L15 | 61.17 | 297.23 | 0.066 |

* I&C is Incision and Chewing

Subject M.W.

Bite force equivalents

|  | Incision | I&C* | Incision / I&C |
|---|---|---|---|
| C2A | 35.81 | 214.94 | 0.167 |
| C2B | 18.49 | 943.04 | 0.020 |
| C2C | 94.23 | 295.69 | 0.319 |
| C2D | 28.57 | 244.15 | 0.117 |
| C2E | 99.71 | 294.45 | 0.339 |
| C20A | 47.48 | 1189.46 | 0.040 |
| C20B | 42.35 | 1233.22 | 0.034 |
| C20C | 55.98 | 930.38 | 0.060 |
| C20D | 64.01 | 1035.73 | 0.062 |
| C20E | 52.91 | 1211.07 | 0.044 |
| L5A | 11.34 | 291.39 | 0.039 |
| L5B | 10.76 | 241.48 | 0.045 |
| L5C | 8.98 | 168.21 | 0.053 |
| L5D | 6.34 | 196.95 | 0.032 |
| L5E | 8.65 | 282.13 | 0.031 |
| L15A | 40.29 | 856.17 | 0.047 |
| L15B | 24.64 | 448.46 | 0.055 |
| L15C | 27.41 | 466.81 | 0.059 |
| L15D | 23.17 | 424.13 | 0.055 |
| L15E | 18.01 | 643.88 | 0.028 |
|  |  |  |  |
| Mean |  |  |  |
| C2 | 55.362 | 398.454 | 0.192 |
| C20 | 52.547 | 1119.972 | 0.048 |
| L5 | 9.216 | 236.034 | 0.040 |
| L15 | 26.702 | 567.891 | 0.049 |
| Standard Deviation |  |  |  |
| C2 | 34.46 | 274.02 | 0.121 |
| C20 | 7.39 | 117.47 | 0.011 |
| L5 | 1.76 | 47.64 | 0.008 |
| L15 | 7.45 | 163.72 | 0.011 |

* I&C is Incision and Chewing