A THREE-DIMENSIONAL ANALYSIS OF ISOMETRIC BITING IN LONG AND SHORT FACIAL TYPES

BY

LAURA REI IWASAKI

A thesis submitted to the Faculty of Graduate Studies
of the University of Manitoba
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ABSTRACT

The facial types exemplified by "long face syndrome" (LFS, dolicofacial type) and "short face syndrome" (SFS, brachyfacial type) individuals are conventionally defined as being very different--morphologically and functionally. The pre-orthodontic treatment records of eight LFS and eight SFS patients from the University of Manitoba Graduate Orthodontic Clinic were selected for analysis and comparison in terms of applied three-dimensional mechanics. The possible functional importance of facial type was investigated for conditions of vertical isometric biting, by employing a three-dimensional numerical model of the masticatory system (Smith et al., 1986).

Commonly used cephalometric landmarks and reference planes were employed for cephalometric measurements. These measurements confirmed clinically recognized differences between the two facial types in terms of anatomic form. The mechanical analysis was carried out for vertical isometric biting, using the plane of occlusion as the plane of reference. Mechanical predictions pertaining to masticatory function were thus derived for each individual set of morphological conditions. These predictions were compared with respect to conventionally defined facial types.

For the given biting conditions, the mechanics of masticatory function predicted by the model for the two facial type groups showed very little difference. This was surprising, in light of the distinction made between the two facial types on the basis of clinical evaluation and

according to conventional cephalometric analyses based on Frankfort horizontal plane (FH) and/or Sella-Nasion plane (SN). A closer analysis revealed that the three-dimensional geometric anatomic relationships for the sixteen pre-orthodontic patients studied were not very different when measured relative to the occlusal plane. It seems, therefore, that the chewing apparatus demonstrates complementary morphological relationships, perhaps the result of strong functional influences on inherent form.

The use of the well known cephalometric reference planes, FH and SN to imply functional characteristics associated with conventionally defined facial types has been shown to be inappropriate. In terms of the functional mechanics of the masticatory system, the occlusal plane is suggested as a more relevant plane of reference. That is, the geometric anatomic relationships important to the function of the chewing apparatus can be better assessed relative to the occlusal plane, than to FH or SN. It seems, furthermore, that "abnormal" dentofacial form as determined relative to FH or SN, may not necessarily imply "abnormal" mechanical function.

A technique for obtaining three-dimensional geometric anatomic data from standardized cephalometric radiographs has been developed. A proposed future use of the numerical model as a clinical, diagnostic tool for the assessment of the mechanics of masticatory function, is supported by this thesis.

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CHAPTER 1 INTRODUCTION

Form and function have been said to be related in both evolutionary and ontogenetic senses. Physical differences and similarities in the facial appearances of individuals and of groups, are commonly acknowledged. The categorization of people on the basis of facial appearance has led to the description of distinct facial types. By extrapolation, these facial types have come to be associated with more than just form.

Facial types have, for instance, come to be associated with predictable personality traits. In the arts, this association is often purposely exaggerated, and hence facial appearances are used deliberately to help to imply physical abilities and to portray particular personality characteristics. Consider Shakespeare's Cassius versus Falstaff for example, as an illustration of this linking of physical and mental traits (Brodie, 1946).

Facial morphology has also come to be associated with biological function. In the clinical sciences, the assumed relationship between craniofacial form and masticatory function is fundamental to many clinical treatment rationales. The validity of this assumption has not been well tested and further work is needed to determine the possible functional relevance of conventionally recognized facial types.

Orthodontics and related fields, have for a long time emphasized the diagnostic importance of facial type in terms of the assessment of current function, potential growth and development, treatment requirements, prognosis for "successful" treatment, and retention of treatment results for a given individual. The so-called dolicofacial (long face) and brachyfacial (short face) types of people have traditionally been seen as being distinctly different in terms of measurable physical features (Dorland, 1974). They are examples of commonly used facial type classifications. Aside from the obvious differences in facial appearance between these two groups, differences in growth and development, general physique, posture, physiology, and personality have also been observed.

People of one facial type are believed to share common esthetic and functional "problems." Strong belief that influential relationships exist between form and function have led to the extrapolation of differences in function associated with these facial types.

Different facial patterns have been recognized and quantified by the measurement of standardized photographs or radiographs. Since the advent of cephalometrics, in the early 1930's, analysis of standardized radiographs of the head has figured prominently in orthodontics and related fields. Cephalometrics has provided a means of describing skeletal and dental morphological relationships not seen or not easily measured clinically.

Cephalometric standards commonly used to distinguish "long face syndrome" (LFS) or dolicofacial individuals from "short face syndrome" (SFS) or brachyfacial individuals, include facial height measurements, expressed as relative proportions of the total anterior vertical face height, and mandibular plane inclinations expressed as an angle measured to some fixed reference plane such as Frankfort horizontal (FH) or Sella-Nasion (SN).

Specific, conventionally employed, cephalometric measurements based on FH or SN reference planes, have been used to identify facial types, and furthermore, have been correlated with certain functional parameters. Strong musculature and increased biting forces are attributed to individuals with short anterior face heights (AFH) and flat mandibular plane angles (MPA), for example. In contrast, those with long AFH and steep MPA are assumed to have relatively weak musculature and decreased biting forces. These relationships are based on experimentally determined statistical correlations, and tend to support clinical impressions. Cephalometric measurements of face height and mandibular plane inclination relative to FH or SN have thus come to imply functional importance.

The consequence of the selection of reference planes to cephalometric and soft tissue analyses has been acknowledged. The frame of reference relative to which other structures are measured, has a strong influence on the interpretive description of a given situation. There is little agreement on the selection of an "ideal" reference plane for cephalometric analysis. So many analyses have employed FH or SN as reference planes, however, that these planes have been largely accepted as standards of orientation.

Other cephalometric planes, relative to which the maxillary and mandibular structures may be measured and assessed, have been advocated. The Bolton plane, which passes through the cranial base, and the Palatal plane, which is the line joining the anterior nasal spine with the posterior nasal spine, for example, have been used in cephalometric assessments and for superimposition. None of these planes have realized the same degree of popularity as FH and SN, however.

The plane of occlusion, or at least a line approximating such a plane, has also been referred to in the literature, but it has not seen extensive use in diagnostic analyses. The definitions of occlusal plane have been many and varied, but two are most common (Moyers, 1979). A line drawn to bisect the mid-occlusal points of the first molars and the incisal overlap of the central incisors has been used. As an alternative, to be used when the central incisors are missing or grossly malpositioned, a line averaging the points of posterior occlusal contact, involving the first permanent molars and primary molars or the bicuspid regions, has also been advocated.

The plane of occlusion is particularly difficult to delineate precisely when the occlusion follows a curve (the Curve of Spee) rather than a plane in the lateral view, and when the dentition is not completely intact. The functional relevance of the occlusal plane should be recognized, however. The occlusion as a particular site or boundary pertinent to the study of craniofacial growth and development, represents the composite effects of both alveolar bone and dental growth. The occlusal junction of the teeth has been regarded as a "specialized kind of movable articulation essentially comparable to other bone-to-bone junctions" (Enlow *et al.*, 1971). It seems however, that despite its conceivable functional relevance to the masticatory system, the occlusal plane has not been a very popular plane of reference because it does not fulfill the standard criteria of accurate identification, or stability over time.

In investigating the suggested relationships between dentofacial form and function, a review of the pertinent literature will be presented to outline the commonly used facial type classifications and to provide some insight into the background influences in devising these classifications. Evidence for the functional importance of dentofacial form with respect to the above mentioned LFS and SFS classifications will also be investigated. As well, examples demonstrating the application of these classifications to orthodontics and related fields will be provided.

Physical anthropology, the theories of evolution, and the concepts of human growth and development in relation to facial morphology have had strong influences on the general regard for facial type. These influences are discussed in detail in Appendix A, and hence, their discussion herein will be brief. The intention of this study is to investigate the morphological relationships pertinent to function. These will be compared with more traditional concepts of "normal" and "abnormal" morphology in terms of esthetics, and as applied to standards of facial type assessment.

CHAPTER 2 LITERATURE REVIEW

I OVERVIEW

Facial typing as it pertains to the classification of dentoskeletal relationships is a widely used clinical tool through which descriptions, diagnoses, treatment regimens, and prognoses are made. To appreciate the origins of the facial types that are currently employed in dentistry, particularly in orthodontics and oral surgery, is to appreciate the words of Brodie (1946):

> Since man's earliest efforts to portray the human, we find notice being taken of certain groupings of characteristics.

The current regard for facial form in orthodontics and dentistry will be discussed. For a better appreciation as to how classifications of morphological type have come about, readers are referred to Appendix A.

Historically, the study of human form and function has been primarily based on visually perceived observations and concomitant descriptive interpretations. These descriptive interpretations have become formalized in the practice of orthodontics such that certain descriptive parameters are accepted almost axiomatically.

The classification of human form has been an important method of appraisal for centuries. A number of different classification systems used to distinguish human body build have been based on anatomical and physiological characteristics. Three extreme patterns of general human body form have usually been differentiated: slender, corpulent, and stocky (Lindegård, 1953). These general body forms have been related to dentofacial characteristics. For example, individuals of extremely sturdy build are said to have larger, broader heads (Lindegård, 1953), as well as larger tooth sizes, earlier tooth eruption, and better response to orthodontic therapy due to better growth (Björk, 1955).

Anthropologists have long used craniometric techniques in the evaluation of human form (Kelso, 1970). Influenced by these craniometric studies of anthropology, orthodontists and others have studied the patterns of association between the head, the face, and the teeth. These associations have been investigated in terms of evolutionary changes as well as ontogenetic changes in an attempt to better understand the link between dentofacial form and function (Downs, 1938; Björk, 1951).

II FACIAL TYPE PARAMETERS

A number of measurements and correlations have gained particular distinction and have found common use in distinguishing and identifying facial types. Observational studies (Wylie, 1945; Ballard, 1951), supported by clinical experience, have firmly established certain parameters as useful clinical tools. These parameters are supposed to provide important diagnostic clues to a more complete pattern of typical characteristics, and therapeutic cues in terms of expected responses and achievable treatment results. The most commonly used parameters will be discussed in the following sections.

1. Mandibular Plane Angle

Form was at one time believed to be strictly inherent, and proportional relationships were expected to remain unchanged from birth to maturity (Brodie, 1941). Angular measures were therefore thought to be particularly useful for the assessment of craniofacial morphology. Angular measures continue to be employed to assess and categorize craniofacial form.

Even before the general acceptance of cephalometrics, measurement of the inclination of the mandibular plane relative to other craniofacial structures had been advocated for clinical diagnosis (Salzmann, 1945). Some form of mandibular plane angulation measurement has been included in most of the classical and popular cephalometric analyses (Margolis, 1947; Downs, 1948; Steiner, 1953; Tweed, 1953; Coben, 1955; McNamara, 1984).

The two planes of reference most commonly used to assess the inclination of the mandibular plane are the Frankfort horizontal (FH) plane and Sella-Nasion (SN) plane. Both the Frankfort horizontal-mandibular plane angle (FHMPA) (Johnson, 1950), and the Sella-Nasion-mandibular plane angle (SNMPA) (Schudy, 1964; Droel and Isaacson, 1972; Bishara and Augspurger, 1975) have been advocated to identify "separate and distinct" facial types.

Generally, clinical populations, divided into groups according to their mandibular plane angles (MPA), have been studied in order to appraise dentofacial characteristics associated with "high" and "low" MPA, as compared to "normal" MPA. Large MPA values have been found to be positively correlated with convex facial profiles where both maxillae and mandibles tended to be in more retruded positions (Schudy, 1964; Bishara and Augspurger, 1975), very small degrees of cranial base flexure (Bishara and Augspurger, 1975), relatively superiorly positioned glenoid fossae (Johnson, 1950; Droel and Isaacson, 1972), small ramal lengths and large gonial angles (Johnson, 1950), upright lower incisors (Johnson, 1950; Bishara and Augspurger, 1975), small vertical overbites (Johnson, 1950; Schudy, 1964), long vertical face heights (Johnson, 1950; Bishara and Augspurger, 1975), and poor facial esthetics (Johnson, 1950). Small MPA values, on the other hand, were found to be associated with straight or concave facial profiles, relatively more protrusive mandibles (Schudy, 1964; Bishara and Augspurger, 1975), glenoid fossae positioned inferiorly in the skull (Johnson, 1950; Droel and Isaacson, 1972), deep overbites (Johnson, 1950), very short vertical anterior face heights (Schudy, 1964; Bishara and Augspurger, 1975), and, depending on the individual case, very poor facial esthetics (Johnson, 1950). High or low values of MPA appear to be associated with predictable dentofacial characteristics.

2. <u>Facial Height</u>

Facial height has been regarded as an important variable in distinguishing facial type. Studies regarding facial balance have shown that increased facial height is generally related to increased gonial angle and a poor facial pattern (Wylie and Johnson, 1952). Ratios or percentages of upper or lower facial heights to total facial height are common cephalometric measurements (Wylie, 1944; Coben, 1955; Goldsman, 1958; Schudy, 1964; Weinberg and Kronman, 1966; Beaton, 1973). The norms or standards of these facial height measurements have varied slightly from analysis to analysis, depending on the sample populations involved.

There has been much controversy regarding the constancy of facial height proportions. The work of Brodie (1941, 1950, 1953) greatly affected the regard for growth and development in clinical orthodontics during the 1940's and 1950's (Tweed, 1946; Wylie, 1946; Downs, 1952; Stoner, 1955). Brodie propounded the concept that the "morphogenetic pattern" of the human head was established at a very early age, and that once attained, this pattern did not change. The percentage contributions of the facial parts to total height were thus believed to remain the same, regardless of age (Brodie, 1941; Hellman, 1932; Broadbent, 1941; Herzberg and Holic, 1943; Wylie, 1944; Tirk, 1948; and Isaacson et al., 1977). Other investigators have contested this belief, however (Williams, 1953; Meredith et al., 1958; Moore, 1959).

3. Mandibular Plane Angle and Facial Height Correlations

A number of investigators have proposed that a compensatory mechanism or balancing property functions within the dentofacial complex to preserve a semblance of overall harmony and proportion in the facial pattern (Tweed, 1954; Coben, 1955; Goldsman, 1959; Hasund and Ulstein, 1970). Where one dimension shows an obvious discrepancy, therefore, other dimensions are compensated in a predictable manner. Significant correlations between facial dimensions that display obvious deviations from mean values typically characterize facial types. It has often been suggested that more than one parameter be used to describe facial type (Coben, 1955; Opdebeeck and Bell, 1978; Fields et al., 1984). The combination of parameters most commonly used to distinguish facial types is the MPA and the lower anterior face height as a proportion of the total facial height (LAFH/TAFH).

Isaacson et al. (1971) examined extreme variations in facial growth in order to compare the morphological differences manifest from these growth patterns. Increased vertical alveolar growth and increased anterior dental height were found in cases of high SNMPA, while decreased vertical alveolar growth and increased anterior dental height were found in cases of low SNMPA. A tendency to anterior open bite malocclusions in high SNMPA cases, was therefore predicted, despite that fact that these patients tend to show relatively longer maxillary incisors. In contrast, a tendency to deep-bite malocclusion in low MPA cases was predicted, despite the fact that these patients tend to show relatively shorter maxillary incisors. Characteristic dentoskeletal morphologies resultant to characteristic patterns of growth, have thus been described.

III DEFINED FACIAL TYPES

In orthodontics and orthognathic surgery especially, interest in craniofacial morphology has been fueled by interests in form and function with respect to treatment. The evolutionary course of man's development from more primitive life forms is believed to be the result of adaptations of shape and structure to changes in function. Many experimental studies on living animals and human subjects have documented growth, development, physiological functions, movements, and associated muscle activity, for example, in relation to anatomical form. This has been in an attempt to establish a basis for the interpretation of observed morphology in terms of functional demands. The rationales supporting the conventionally accepted classifications of facial form, and the functional characteristics generally associated with these, are to be found in the literature describing the theories of craniofacial growth and development with respect to form and function. From these theories come the bases for the clinical applications of facial type classifications in terms of treatment for "abnormal" form and "abnormal" function. This literature will now be explored.

1. Characterization

The term "long face syndrome" (LFS) has been used to describe individuals showing excessive anterior vertical facial dimensions relative to posterior facial dimensions (Schendel *et al*., 1976; Radney and Jacobs, 1981; Proffit and Fields, 1983; Fields *et al*., 1984). This so-called "syndrome" is characterized primarily by an excessive nose-to-chin length (LAFH) and a steep mandibular plane angle. Other characteristics which have been included in the "syndrome" are: a narrow alar base and nostrils that are small and poorly developed; a poor upper lip-to-tooth relationship with inordinate exposure of maxillary teeth and gingiva upon smiling; a large interlabial gap; a short ramus; a retruded mandible, a long, narrow, v-shaped maxillary arch with a high palatal vault, proclined upper incisors, and a large distance between the maxillary root apices and the nasal floor. Tendencies toward a skeletal anterior open bite, an open mouth posture, and a vacant facial expression have also been associated with large LAFH and steep MPA (Linder-Aronson and Backstrom, 1960; Linder-Aronson, 1970; Schendel *et al*., 1976; Radney and Jacobs, 1981; Shaughnessy, 1983). Among other terms used to describe this facial type are: extreme clockwise rotation (Schendel *et al*., 1976), high angle type (Schudy, 1966), adenoid facies (O'Ryan *et al*., 1982), idiopathic long face (Willmar, 1974), total maxillary alveolar hyperplasia (Hall and Roddy, 1975), and vertical maxillary excess (Schendel *et al*., 1976).

The opposite condition of short LAFH and low MPA has been termed "short face syndrome" (SFS) (Bell, 1977). Individuals manifesting similar skeletal, dental, and facial features as a result of a lack of vertical maxillary growth, characteristic of the SFS (Bell, 1977), have been described under a number of different terms, such as: hypodivergent face (Schudy, 1965), low-angle type (Schudy, 1966), skeletal type deep-bite (Sassouni, 1969), idiopathic short face (Willmar, 1974), vertical maxillary deficiency (Opdebeeck and Bell, 1978), and extreme counterclockwise rotation type (Opdebeeck and Bell, 1978). Clinically, the typical SFS presents with an edentulous, overclosed appearance in a short, square-shaped face; often with a distinct chin button, deep mentolabial fold, and a tendency to skin-folds lateral to the oral commissures. The masseter muscles are generally well developed, the vertical maxillary height is small, the interocclusal distance large, and there is a large overbite along with the short LAFH and low MPA (Van Sickels and Ivey, 1979).

Use of the term "syndrome" has been justified by Opdebeeck and Bell (1978) since, for a given facial type, similar esthetic, cephalometric, and occlusal features are consistent and thus can be grouped together. The general terms LFS and SFS have been used to allow a less restricted, more complete description of the skeletal, dental, and facial characteristics of a given type and its variants.

The LFS and SFS individuals represent extreme dysplasias in terms of skeletal, dental, and facial structures. Surgical treatment to improve the hard and soft tissue relationships is often advocated in such cases (Bell, 1977; Van Sickels and Ivey, 1979; Piecuch et al., 1980; Radney and Jacobs, 1981). It is felt to be indicated on the basis of compromised esthetics and function due to extreme morphological deviations from accepted human norms.

2. Theories Regarding Form and Function

i. Breathing and Posture

Mouth-breathing due to impaired nasal respiration has often been discussed as a major etiological factor in cases of LFS (Linder-Aronson, 1979; Vig, 1981; O'Ryan et al., 1982; Quinn, 1983). Although commonly observed and frequently reiterated (Brash et al., 1956), the causal relation between respiration, posture, and deformities in the dentofacial complex have yet to be substantiated by well-controlled experiments carried out on human subjects. Studies have shown respiration (Riski, 1984) and posture (Eliasson, 1975) to be highly variable within the same individual. Methods of accurately assessing respiration have so far not been available for use in prospective, longitudinal, clinical studies (Vig, 1981; O'Ryan et al., 1984; Warren, 1984). Although evidence from animal experiments (McNamara, 1977; Harvold, 1979; Tomer and Harvold, 1982; Miller et al., 1984; Ramadan, 1984) would seem to demonstrate support for significant parallels between mouth-breathing in humans and LFS, the validity of extrapolation to the human situation is questionable.

A relationship between head posture and craniofacial morphology was first suggested by Schwarz in 1926 (Solow et al., 1984). He attributed the development of Class II malocclusions to the hyperextension of the head relative to the cervical column during sleep. Since then, many associations have been made between airway adequacy, craniocervical posture, and craniofacial morphology. It has been postulated that mouth-breathers tend to tip their heads backwards in an attempt to increase their airway. Where adenoidectomies have created a normal airway, a less extended head posture has been reported (Ricketts, 1968; Linder-Aronson, 1974; Woodside and Linder-Aronson, 1979; Solow and Greve, 1979). Furthermore, a radiographic study done by Shelton and Bosma (1962) on pharyngeal airway patency showed this patency to be markedly increased in radiographs taken with the head extended.

"Forward head posture," is known to have whole-body ramifications. A chronology of events is associated with this "abnormal" postural position, which can affect "muscle length/tension relationships and joint biomechanics" (Darnell, 1983). Solow and Tallgren (1977), found that subjects with large craniocervical angulation tended to have decreased facial prognathism, a large mandibular plane inclination, and a large LAFH. A hypothesis to account for the association between head position, decreased nasal airway function, and craniofacial morphology has suggested a chain of interactions involving:

1) change in airway adequacy
2) neuromuscular feedback
3) change in craniocervical angulation
4) passive stretching of the soft-tissue layer covering the face and neck
5) morphologic change
6) change in airway adequacy.

-Solow and Tallgren (1977)

"Triggering factors" are also thought to be involved: adenoid tissues, perennial allergic conditions; disturbances in the visual, proprioceptive, utricular, or semicircular canal systems; cervical spine anomalies; scar tissues; and sutural growth disorders, condylar disorders, or a discrepancy between the vertical components of condylar and cervical vertebral growth (Solow et al., 1984). Investigations to test the possible correlations between nasal respiratory resistance and craniocervical angulations have been carried out (Solow and Greve, 1979; Linder-Aronson, 1979; Weber et al., 1981; Solow et al., 1984).

The effects of tongue and mandibular posture, on the dentofacial morphology have been explored for real and simulated anterior open bite subjects using EMG recordings of the activity of the tongue, the jaw, and the orofacial musculature (Lowe, 1980). Although relationships have been suggested, the small sample sizes preclude any definite conclusions from these studies. Daly et al. (1982) found that, a mechanical bite-opening of eight millimeters caused changes in head posture in their clinical subjects. These were largely due to extension of the neck, and were induced within one hour. The subjects tended to recover their original head posture after removal of the bite-opening device, leading to speculations that the response was related to functional demands and influences. The maintenance of a postlingual airway and/or occlusal sensory perception and a subsequent motor response have been suggested in this regard.

With the increasing prevalence of the surgical correction of craniofacial deformities, concern has been raised over the effect of such surgery on nasal airway resistance, especially where vertical changes to the maxilla are involved. It is hoped that the suspected cause-effect relationship between nasal airway and craniofacial charcteristics, and the part played by posture, muscular activity, and oral habits will be investigated through the study of the effects of orthognathic surgery. The current literature in this area has described preliminary research only (Grandstaff and Mason, 1983; Turvey et al., 1984; Guenthner et al., 1984).

ii. Muscles

Links between the neuromuscular and skeletal systems are known to exist (Harvold, 1979) however, the nature of the relationship between form and function has yet to be determined. The question of whether a predetermined facial form dictates muscle strength or whether muscle strength determines the facial form remains.

Experimental investigations have consistently shown type-specific muscle characteristics associated with the masticatory systems of LFS and SFS individuals. Correlations between the masticatory muscle electromyographic (EMG) activity and facial and bite morphology have been found in children (Ahlgren, 1967; Ahlgren et al., 1973; Ingervall and Thilander, 1974) and adults (Møller, 1966). Similar results have been obtained from studies of isometric bite force in adults (Ringqvist, 1973). For the conditions of chewing, biting, swallowing, and postural rest position, these studies have shown increased masticatory muscle activity and increased biting force in individuals with SFS characteristics (Ahlgren, 1967; Møller, 1966; Ringqvist, 1973; Ingervall and Thilander, 1974; Ingervall, 1976). These individuals exhibited small face height; parallelism between jaw bases, occlusal line, and the mandibular border; and a small gonial angle.

Møller found that certain features of facial morphology varied less within a group of persons with strong masticatory muscles than with weak masticatory muscles (Ingervall and Helkimo, 1978). Strong muscles therefore resulted in faces with similar morphological features, whereas weak muscles, which were less able to influence morphology, resulted in a wide range of variation in individual facial patterns.

Ingervall and Helkimo (1978) studied young adults with complete, natural dentitions, to measure bite force and to examine them for signs and symptoms of functional problems within their temporomandibular joint systems. The sample was represented by strong and weak bite force groups. No significant difference with respect to signs and symptoms of temporomandibular joint dysfunction (TMD) was found, except the strong bite group as a whole showed increased tooth abrasion. A link between bite force, tooth position, and facial morphology has been pointed out by others as well (Richards, 1985). Strong bite force was presumed to imply strong muscle force, although muscle activity was not actually measured. A comparison of cephalometric parameters used to measure facial morphology supported the work of Møller (Ingervall and Helkimo, 1978), in that a greater uniformity in facial morphology was shown in those with strong bites. Ingervall and Helkimo therefore concluded that the effects of muscles contribute to the shape of the face. The cranial base, on the other hand, seemed to be governed by intrinsic factors, since it was found to be variable in both strong and weak bite groups (supporting the theories of van Limborgh, 1972). The essential morphologic differences between the weak and strong bite groups were thus: decreased facial height and decreased mandibular plane inclinations in the strong bite group relative to the weak bite group.

Investigations into vertical facial dysplasias with respect to muscle morphology, muscle activity, and muscle mechanics, have been described. Finn and co-workers (1980) obtained muscle biopsies of the deep masseter from three LFS and three SFS surgery patients, and from three normal cadavers, for histological examination. The type and distribution of the component muscle fibres are generally felt to be a reflection of the function of the muscle as a whole. Signs of muscle fibre hypertrophy were found in long-faced patients, while signs of muscle fibre atrophy were found in short-faced patients compared to the controls. This initial histological study has suggested that patients with vertical maxillary dysplasia have abnormal jaw muscles.

EMG results of the muscle activity in LFS compared to SFS patients have been quite consistent, in that higher EMG activity of the muscles has been seen in short-faced subjects (Møller, 1966; Ahlgren, 1973; Ingervall and Thilander, 1974; Ingervall, 1976; Finn et al., 1980). On the basis that the force that a muscle fiber can generate is proportional to the cross-sectional area of the fiber, it has been argued that short-faced patients must recruit more muscle fibres to generate the same bite force as long-faced patients (Finn et al., 1980). A two-dimensional analysis of the masticatory system of short-faced patients compared to long-faced patients did not show large differences in the mechanical advantage between the two groups, however. Finn et al. concluded, therefore, that differences in muscle morphology masked the relatively small mechanical differences that might have existed.

The total muscle fibre cross-sectional area has been assumed to be a measure of the maximal isometric strength of a muscle. Cross-sectional areas of the masticatory muscles have been investigated in cadaver material by Weijs and Hillen (1984a and 1985). Cross-sections taken from computer tomograms taken at pre-defined levels in the muscle were found to be proportional to the anatomically determined total fibre cross-sectional area. The relationships between the cross-sectional areas of the masticatory muscles and the dimensions of the face and cranium in clinical subjects with "normal" occlusion have also been studied (Weijs and Hillen, 1984b). In general, the breadths of the skull, face, and mandible were found to be strongly correlated with the strength of the masticatory system. The masseter and medial pterygoid muscles were found to be large in individuals with brachycephalic skulls, short faces, and small gonial angles. The cross-sectional areas of the temporalis and lateral pterygoid muscles, however, showed no significant correlation with facial dimensions. This lack of correlation between the cross-section of the temporalis (the largest jaw muscle), and craniofacial form, was surprising. Since the temporalis varied less in cross-section than the other jaw muscles and showed a relatively weak correlation with the total jaw muscle cross-section, it was suggested that the strength of the temporaralis muscle may be a constant factor in the chewing system, and that the masticatory strength is modulated by the masseter and medial pterygoid muscles (Weijs and Hillen, 1985).

iii. Bite Force

The magnitude of the biting force has been presumed to be related to muscle strength (Ingervall and Helkimo, 1978;

Kawazoe et al., 1979). In a study of bite force (simulating that used in chewing) and finger force however, Helkimo and Ingervall (1978) showed no correlation between bite force (or chewing force) and the general muscle strength as represented by finger force. This was in agreement with the findings of Lindholm and Wennström (1970) who failed to show statistically significant correlation between bite force and general muscle force, body height, weight, and skeletal dimensions.

It has been suggested that for a given individual, a vertical dimension exists from which maximum masticatory force may be developed (Boos, 1940; Tueller, 1969). This position is believed to be close to the mandibular postural rest position. Manns and associates (1979) investigated these findings by recording masseter muscle EMG activity and the bite force during isometric biting at various vertical dimensions in healthy adult subjects. An optimum vertical dimension was found to exist, for these individuals, between fifteen and twenty millimeters from occlusion. This position, where the bite force was maximized and the EMG activity of the masseter muscle was minimized, was considerably larger than the conventionally accepted ranges for rest position interocclusal distance. It was concluded that this represented a physiologically optimum muscular elongation of major efficiency for the masseter muscle, and that individual differences in this position probably corresponded to differences in craniofacial skeletal characteristics.

Investigations by Proffit, Fields, and Nixon (1983a) have demonstrated significant differences between occlusal forces in adults with normal vertical dentofacial proportions and those with LFS vertical dysplasias. At maximum effort, the LFS individuals were shown to have about half as much biting force as the normal individuals. The LFS subjects also showed considerably less occlusal force during simulated chewing, and were found to bring their teeth together with significantly less force during swallowing than did the normal group.

A similar study was carried out by Proffit and Fields (1983b) to investigate the occlusal forces in normal and LFS children. They hoped to discern the possible etiological significance of bite force in the LFS; that is, whether lower occlusal forces in LFS adults cause the development of long vertical facial proportions, or whether long vertical facial proportions account for relatively lower occlusal forces. The forces of dental occlusion measured during swallowing, simulated chewing, and hard biting were found to be similar for both the long-face and normal children. These forces were similar to those found in long-face adults, or about half of those found in normal adults. Proffit and Fields (1983b) thus concluded that individuals with LFS fail to gain a normal level of strength in the muscles involved in biting.

The clinical importance of facial type recognition in treatment involving occlusal changes has been pointed out.

Evidence for a relationship between facial types distinguished by FMPA, patterns of tooth contact in eccentric jaw movements (lateral disclusion), and biting forces has been presented (Dipietro, 1977).

iv. Vertical Dimension

The effect of the maxillary and mandibular denture relationships on facial height has been debated, primarily in the prosthodontic literature. Rugh and Johnston (1984) have provided a comprehensive summary of the controversy surrounding the stability of the vertical dimension (the facial height as determined by the teeth, their supporting structure, and the jaw-positioning muscles) in the clinical subject. The confusion lies in whether or not the vertical dimension can be changed by restorations or orthodontic therapies. It has generally been felt that the neuromuscular system determines the optimum vertical dimension for the individual. This position is commonly regarded as critical and relatively stable. If violated beyond the range of tolerance of a given individual, the general consensus is that a predictable sequence of events occurs which is believed to be deleterious to the individual. The predicted results have included: muscle hyperactivity, extrusion or intrusion of teeth, possible loss of periodontal support, and, in the edentulous patient, dental prostheses failure (Rugh and Johnston, 1984).

With respect to the effects of orthodontic treatment on the vertical dimension, anterior face height and the variations in its components, have been investigated for individuals with deep-bite malocclusions (overbite greater than five millimeters). Orthodontic treatment was found not to significantly alter the anterior facial proportions, in spite of successful correction of deep overbite malocclusions, involving a significant change in the dental components of facial height (Weinburg and Kronman, 1966). Speculations that the masticatory muscles were responsible for maintaining facial proportions by acting to maintain their resting length, and that the decrease in overbite with treatment was due to depression of the mandibular incisors, have thus been made.

The role of vertical dimension discrepancies of the jaws has figured prominently in the quest to understand masticatory pain and dysfunction. Cases of SFS and LFS, where surgical rearrangement of maxillary and mandibular relationships are carried out, may, in the future, help to resolve the controversy regarding the sanctity of vertical dimension.

3. Dysfunction as a Basis for Treatment of LFS and SFS

The mechanical, occlusal, and neuromuscular theories pertaining to the functional characteristics of SFS and LFS affect the assessment, treatment, and prognosis for individuals where external intervention to achieve morphological changes is contemplated.

Three basic views have prevailed. The mechanical view pertains to anatomical positioning and the compromised relationship of the condyle to the temporal fossa in cases of changes to the vertical dimension. "Overclosure" is of particular concern (Costen, 1934; Harris, 1938). The occlusal view pertains to poor tooth-to-tooth relationships causing displacement of the mandible during function, particularly in a posterior direction. This results in compression of the highly vascular, densely innervated, loose retrocondylar connective tissue (Thompson, 1951; Hankey, 1954; Granger, 1958). The third view is the neurophysiological view, which pertains to muscular dysfunction due to altered proprioceptive feedback and involving higher centres of control (Laskin, 1969).

The concept that a malocclusion may initiate occlusal disharmonies leading to hyperactivity of the masticatory musculature and temporomandibular joint pain and dysfunction (TMD), has long been held. Many surveys have been conducted in an attempt to evaluate the significance of Angle classification malocclusions and/or skeletal problems to the prevalence of signs and symptoms of TMD (Egermark-Eriksson et al., 1983; Upton et al., 1984; Mohlin and Thilander, 1984). This classification system has notable limitations (strictly speaking, it implies anteroposterior discrepancies only), but it is used so commonly as a basis for diagnosis and treatment, that evidence for a correlation of Angle classification "types" to TMD has been actively sought.

Clinical impression has suggested that Angle Class II skeletal and dental patterns with vertical dysplasias show signs and symptoms of TMD most frequently. Deep bites, characteristic of Angle Class II, Division two malocclusions have been commonly reported in clinical TMD sample groups (Perry, 1969; Mongini, 1977; Williamson and Brandt, 1981) as have skeletal anterior open bite malocclusions (Perry, 1969; Williamson and Brandt, 1981; Mohlin and Thilander, 1984; Thilander, 1985).

Currently, there is little agreement on the association between abnormal skeletal and/or dental relationships and temporomandibular pain and dysfunction, including internal joint pathology and abnormalities of muscle function. What constitutes "dysfunction" has been controversial and poorly defined (Moyers, 1985). The sample selection of most studies have therefore been based on poor criteria. Greene and Marbach (1982) have suggested that any relationships between dental malocclusion, abnormal facial morphology, and TMD have been greatly exaggerated. Their critical analysis of the epidemiological research in this area provides good argument against the clinical application of the information gained from such studies.

Van Sickels and Ivey (1979) have presented a rationale for the association of SFS with myofacial [sic] pain dysfunction syndrome. Myofascial pain dysfunction syndrome (MPD) is recognized as a multifactorial entity related to the anatomy of the temporomandibular joint, the muscles of mastication, the occlusion, and the personality of the patient. It has been suggested that SFS represents an anatomic variation which simulates the situation of overclosure due to loss of vertical dimension in the prosthodontic patient (Van Sickels and Ivey, 1979; Piecuch <u>et al</u>., 1980). This so-called overclosure, is purported to cause the muscles to overcontract and result in muscle fatigue, and furthermore, to result in posterosuperior repositioning of the condyles, leading to joint noises and altered mandibular movements. Treatment to address both the MPD and the underlying anatomic variation has been advocated (Van Sickels and Ivey, 1979; Piecuch <u>et al</u>., 1980). Occlusal splint therapy in order to temporarily attain a more normal vertical dimension, followed by a maxillary osteotomy procedure to permanently improve function and esthetics, have been suggested in cases of SFS (Van sickels and Ivey, 1979). Resolution of TMD problems in a SFS patient, who underwent orthognathic surgery to establish more normal skeletodental relationships, has been documented (Piecuch <u>et al</u>., 1980). More substantial evidence is needed, however. Treatment rationales such as these require more thorough investigation before being applied to the general SFS population, or to the skeletal dysharmony population as a whole.

A number of studies to investigate the prevalence of TMD in skeletal disharmony groups or subgroups have been carried out. Rotskoff has reported a forty-three percent incidence of TMD symptoms in a population of one hundred and forty-one pre-orthognathic surgery patients (Upton <u>et al</u>., 1984). Upton and associates found an incidence of pretreatment TMD symptoms in orthognathic surgery patients of fifty-three percent, but this was based on a postreatment, retrospective questionnaire, to which less than half of their patients responded.

Wisth (1984) has looked at TMD signs and symptoms in patients with mandibular prognathism. He reported a significantly greater incidence and severity of certain TMD signs and symptoms in untreated prognathism patients than in those who were treated surgically ten years earlier. He therefore suggested that surgical repositioning of the mandible to a more normal position may decrease TMD by securing a more normal pattern of mandibular function.

There has been relatively little published work describing how major skeletal disharmonies such as those seen in LFS and SFS relate to TMD. Yet there is a strong implication that in cases such as LFS and SFS, where occlusal and facial morphology deviate form the "normal" or "ideal," that correction in the form of dental and/or surgical treatment is needed to not only improve esthetics, but to improve function and possibly avoid future functional problems (Kwon et al., 1984). In terms of function, "prophylactic" treatment is felt to be justified even when no pre-treatment signs or symptoms of any pathology or mandibular dysfunction can be demonstrated (Greene and Marbach, 1982).

Evidence from other studies has shown the incidence of the signs and symptoms of TMD in the general population to be quite high (Rieder, 1977; Helkimo, 1976; Greene and

Marbach, 1982). As well, emotional and psychological factors are known to be involved (Laskin, 1969; Zarb and Speck, 1977). Yemm (1979), has supported the argument that TMD represents a centrally derived disturbance rather than a result of functional dysharmony dictated primarily by abnormal morphology.

In a survey of the oral and maxillofacial surgery training programs at major universities and hospitals in the United States, Laskin and associates attempted to determine what the experience of TMD in orthognathic surgical patients had been in the various centres (1986). Responses were received from the staff of fifty-one of the one hundred and sixteen programs. Representatives of the programs, in most cases, reported fewer than twenty percent of their patients as having symptoms of TMD (mean, 14%; median, 10%). Two respondents claimed to see such problems in seventy-five percent of their patients, while five respondents reported that no patients with symptoms of TMD were found in their screened populations. According to the responses, the majority of the potential orthognathic surgery patients being screened in these programs did not appear to exhibit symptoms of TMD. Clearly, however, wide variation existed in the reponses from the various centres. Laskin and associates have suggested that these variations reflect differences in the criteria that clinicians use to diagnose TMD, as well as differences in their perceptions and attitudes about the etiologic importance of gross skeletal dysharmonies in cases of TMD. Three major problems arise from errors of improper classification (Laskin _et al._, 1986). Firstly, a misunderstanding can be created about how common it is for TMD to develop in patients with skeletal dentofacial dysharmonies. Secondly, a presumptive and possibly erroneous causal association has been made when a patient with a major skeletal dysharmony has symptoms of mandibular pain and dysfunction. Finally, the need for correction of these dysharmonies appears more imperative if surgeons and orthodontists believe that patients with major malocclusions either are at high risk of TMD or must have orthognathic treatment in order to resolve symptoms that are present. Data to support an association between skeletal dysharmonies and TMD has so far been insufficient to be a strong basis for clinical treatment.

4. Mechanical Analysis

Investigations into the mechanics of various masticatory systems as dictated by morphology have been attempted. O'Ryan and Epker (1984) have pointed out variations in the temporomandibular joint morphology between Class I normal, Class II open-bite, and Class II deep-bite variants. They have suggested that since such morphological differences are predictable, predictions as to temporomandibular joint problems, particularly with respect to joint loading should also be possible.

Throckmorton and associates (1983) have presented the results of a model analysis demonstrating how selected differences in facial morphology should affect the mechanical advantage of the masticatory muscles. The model was used to evaluate differences in the mechanical advantage between patients with LFS and those with SFS. Although Throckmorton and associates predicted that differences in facial morphology between the two extreme facial types resulted in significant differences in the mechanical advantage of their muscles, their model analysis was strictly two-dimensional. Extrapolation to the clinical situation to predict the effects of orthognathic surgical procedures or masticatory function, therefore, is highly questionable.

Various other models of the masticatory system have been proposed as well (Barager and Osborn, 1984; Osborn and Barager, 1985; Smith _et al_., 1986; Meyer and Fields, 1986; Hatcher _et al_., 1986), but no three-dimensional analyses of the mechanics of masticatory function with respect to facial type have yet been reported.

CHAPTER 3 METHODS AND MATERIALS

I OVERVIEW

Individuals with gross morphological differences are expected to function differently. On this basis, an initial evaluation of isometric biting in two facial types was undertaken. A numerical model was employed to compare the mechanical aspects of the masticatory system as governed by anatomical relationships important to static bite situations. Individuals were assessed clinically and cephalometrically, and selected to exemplify two very different types of facial morphology. Each individual was analyzed for comparison in terms of the mechanics of their chewing apparatus and their functional anatomy, with respect to conventionally defined facial types.

II DESCRIPTION OF THE MODEL

The numerical model used for this study is an iterative, three-dimensional model of the masticatory system, similar to that developed by McLachlan and Smith (Smith et al., 1986). Under normal biting conditions the mandible is assumed to undergo negligible accelerated motion. It may therefore be regarded as a rigid body. Since the gross anatomical parameters, and hence, the mechanical parameters for an isometric bite can be fully defined, a numerical solution to describe the requirements for static equilibrium in a given system can be reached. The McLachlan-Smith model employs Newtonian principles to predict muscle activity patterns and condylar load patterns relative to an applied bite force. The premise that the temporomandibular joints should be minimally loaded for any given bite force consistent with mechanical equilibrium, is the basis for this numerical model.

The term "loading," as it pertains to the temporomandibular joint, has been defined in this model as a force acting upon the condyle and imparting to the condyle a propensity toward linear movement (Smith, 1984). "Load," for the purposes of this presentation will be used synonomously with the term "force" and thus will have the properties of magnitude, direction, and point of application. For any situation in which the condyles have a propensity for movement, regardless of the direction, the temporomandibular joints will be considered to be loaded. Forces directing the condyle towards its articular eminence will be regarded as appositional loads. Forces directing the condyle away from its articular eminence will be regarded as distracting loads.

The spatial relationships of the particular chewing apparatus to be represented in the model were measured orthogonally relative to the plane of occlusion and the intercondylar axis (Figure 3.1). Thus, the relative positions of the tooth row, condyles, and muscles involved in biting are described by coordinates (x,y,z) from an origin at the centre of the inter-condylar axis. These numerical data form the major data set for the model. The "natural" or "functional" occlusal plane, as defined by

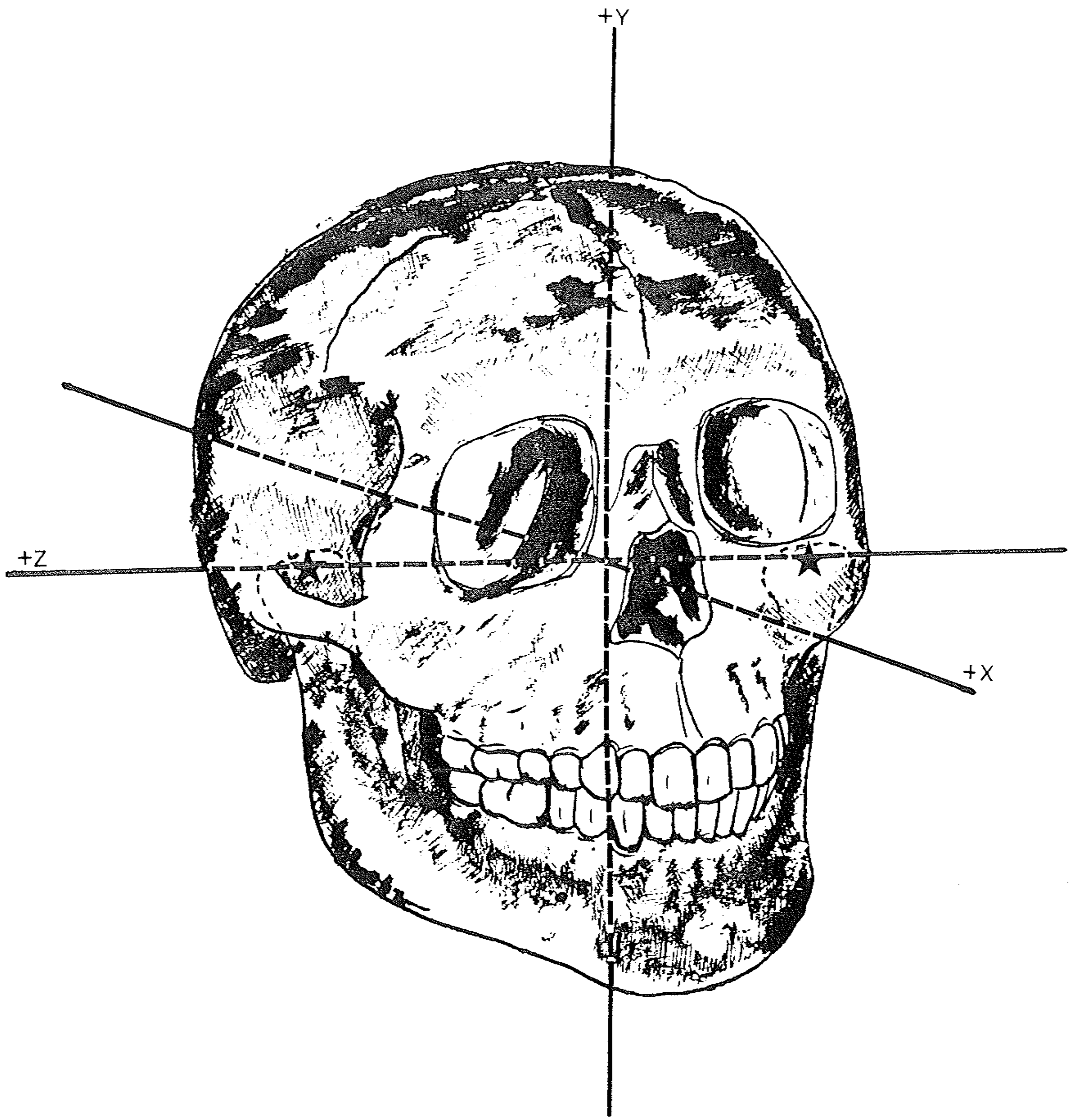


Figure 3.1 ORTHOGONAL AXES FOR SPATIAL RELATIONSHIPS

Moyers (1979), has been modified for use in the model. Moyers defined the sagittal view occlusal plane as being represented by a line averaging the posterior occlusal contacts, usually involving the first permanent molars and the primary molars or the bicuspids. For the model, the occlusal plane was a plane averaging the points of posterior occlusal contact from the distobuccal cusp of the mandibular second permanent molar (2m), anteriorly through the bicuspid region, and crossing within the area between the incisal edge and the incisal one-quarter of the most anterior mandibular tooth (Figure 3.2). The criteria for determining occlusal plane were applied in the following order:

1) the point of contact at the distobuccal cusp of the 2m
2) a point between the incisal edge and the incisal one-quarter of the central incisor; or the most anterior mandibular tooth involved in function
3) the best plane averaging the points of occlusal contact between points 1) and 2).

The x-z plane is parallel to this occlusal plane, while the x-y plane and y-z plane are perpendicular to this occlusal plane.

In cases where all the mandibular teeth are intact, well-aligned, and show minimal curve of Spee (the curve to the plane formed by the biting surfaces of the teeth), the occlusal plane is quite easily determined by this definition. Cases with malocclusions where the teeth are grossly malpositioned and/or there is a significant curve of Spee however, require a greater degree of operator judgement and are subject to more variability.

The z-coordinates completing the three-dimensional

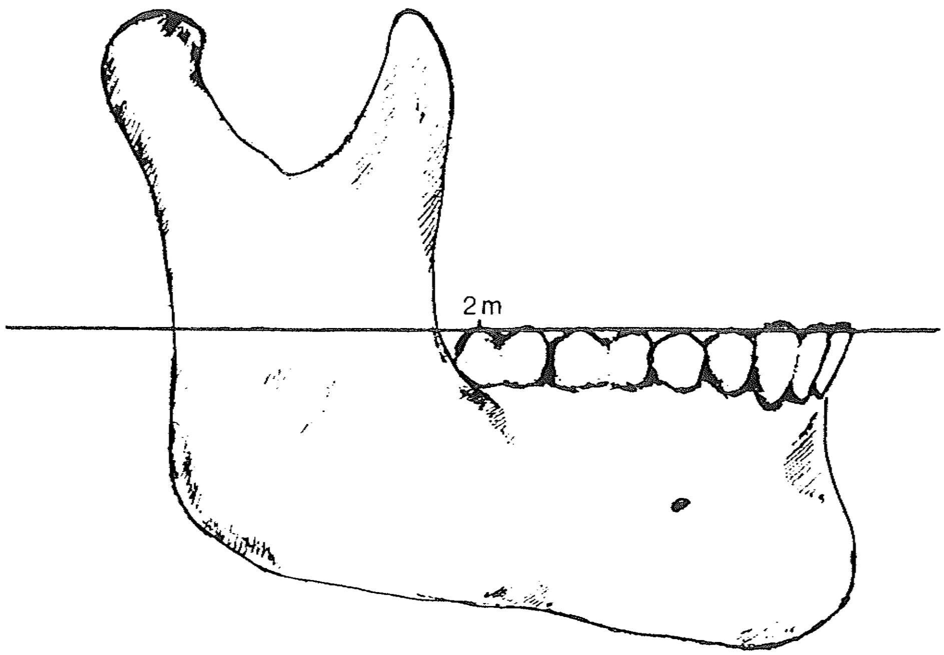


Figure 3.2 OCCLUSAL PLANE IN THE SAGITTAL VIEW

description of the tooth row are given by the positions of the cusp tip of the mandibular canine and the distobuccal cusp tip of the mandibular second permanent molar. The tooth row is thus approximated by two straight line segments representing the right and left mandibular teeth from the distobuccal cusp of the second permanent molar to the canine, and by the arc of a circle representing the mandibular anterior teeth (Figure 3.3).

The most anterosuperior point on the sagittal view profile of the condyle, and approximately midway mediolaterally, represents the temporomandibular articulation for the right and left condyles (Figures 3.2 and 3.3). A line joining these two points has been defined here as the intercondylar axis (z-axis in Figure 3.1).

The resultant force and the resultant moment acting on the mandible are zero when static equilibrium is satisfied. A bite force applied at a point on the tooth row must therefore be resisted by the condyles and by the contraction of muscles. Six muscles of mastication that are involved in jaw closure are represented in the model; these are the right and left masseter muscles, the right and left temporalis muscles, and the right and left lateral pterygoid muscles. The biting system has been simplified to investigate vertically applied biting loads. The medial pterygoid muscles, which are thought to be important in resisting mediolateral loads to the jaw, have therefore been excluded.

The six muscle vectors are determined from estimates

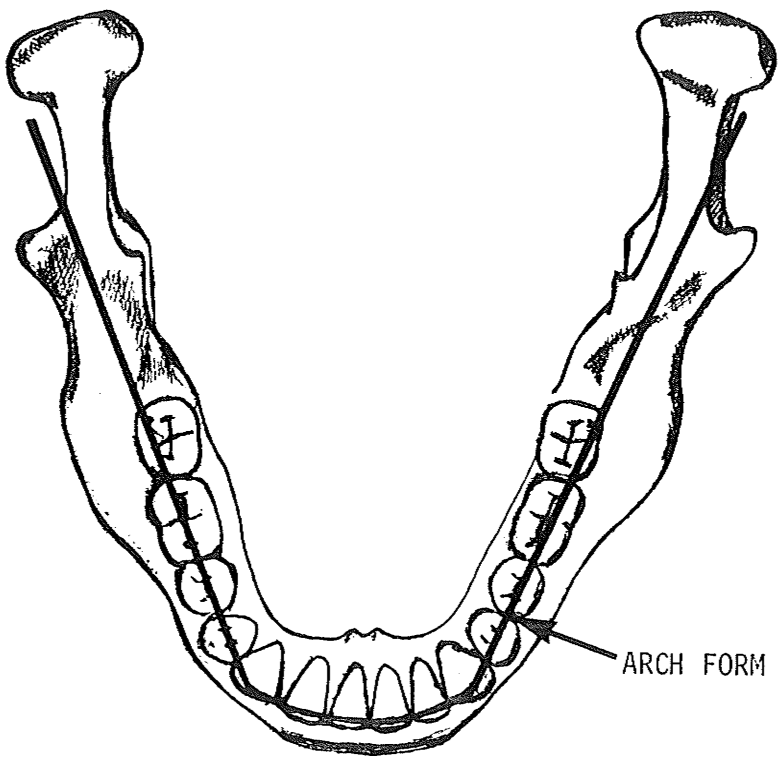
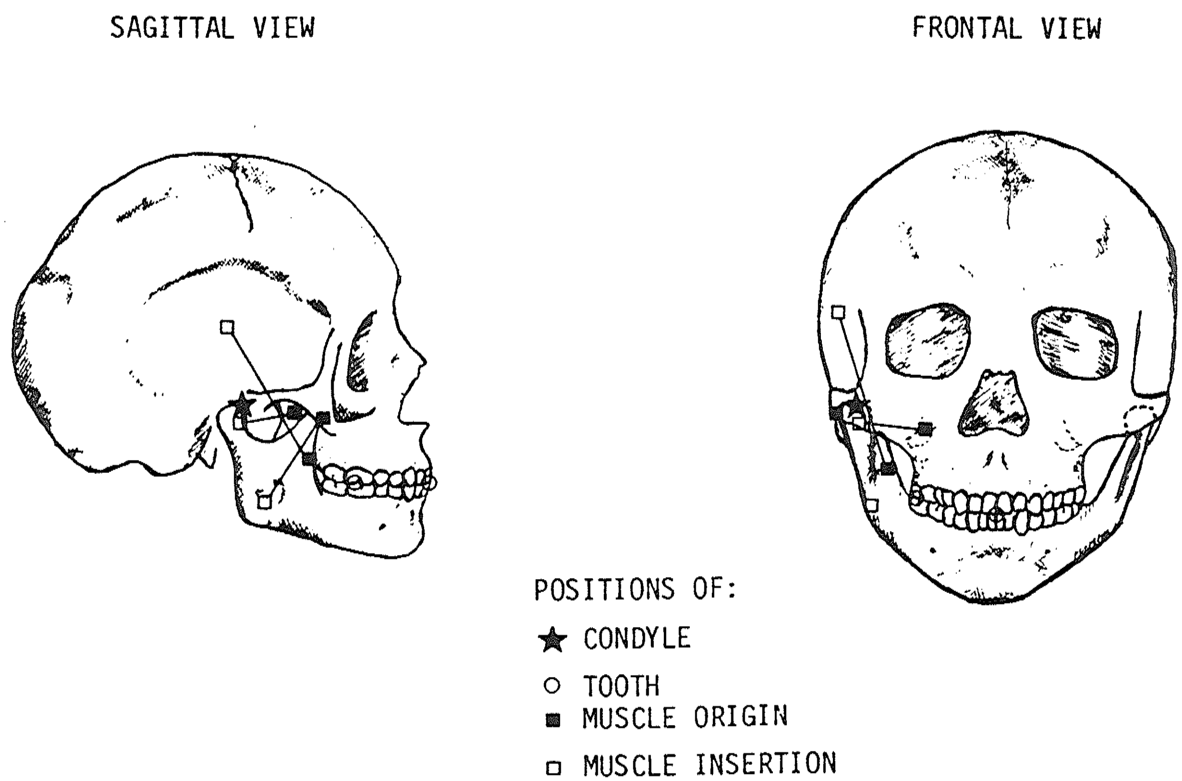


Figure 3.3 OCCLUSAL VIEW OF MANDIBULAR DENTAL ARCH

of the muscle centroids corresponding to muscle insertions and origins, as determined by anatomic landmarks. For isometric biting, because muscle attachments are fixed to bone, and because the forces created by muscles come about only through contraction, these muscle vectors will be of a set direction and point of application. The contraction forces required to satisfy static equilibrium are thus represented as single resultant vectors. The relationship between these muscle vectors, for a given biting situation, will depend on the anatomical relationships of the origins and insertions for an individual. Within an individual system, the muscle vectors can be moved to accommodate variations in function. For example, posterior biting with the mandible in a retruded position, as well as anterior biting with the mandible in a protruded position, may be investigated in the model (Nickel, 1987).

The basic information required for the numerical model analysis of a particular biting situation is provided by the geometric anatomic data representing a given system. The relative positions of the occlusal plane, the condylar heads, and the muscle vectors of the masseter, temporalis, and the lateral pterygoid muscles, are measured from dental and skeletal landmarks and hence are known (Figure 3.4). The bite force, its point of application, and the direction of its action on the mandible are specified by the investigator, and therefore are also known. Given the condition that the forces acting on the condyles should be minimized, a two-step algorithm is employed to solve for the



3.4 GEOMETRICAL RELATIONSHIPS

unknowns: the muscle force magnitudes and the magnitudes and directions of the forces on the condyles (Figure 3.5). A computer program was developed to conduct the iterative calculations required to reach a solution.

The muscle force magnitudes required to minimize condyle force magnitudes for static equilibrium in three-dimensions, are thus determined by the numerical model when a chosen bite force is applied at a specified point along the tooth row. Vertical bite forces, which have been assigned an arbitrary magnitude of one hundred units have been used. The predicted muscle force and condylar load magnitudes are expressed relative to this percent of bite force. For a more detailed mathematical description of this numerical model readers are referred to Smith's work (1984).

III DESCRIPTION OF THE SAMPLES

Investigations regarding the functional morphology of the human masticatory system have been carried out using the described model (Smith et al., 1986; Nickel, 1987). The geometric anatomical relationships required for these investigations have been obtained through direct (Smith, et al., 1986) and indirect (Nickel, 1987) measurements of human skeletal material. A method of deriving the required anatomical data from living human subjects for use in the model, is seen as potentially valuable to clinical investigations of the human masticatory system.

A method employing the cephalometric radiographic records commonly used by orthodontists for patient

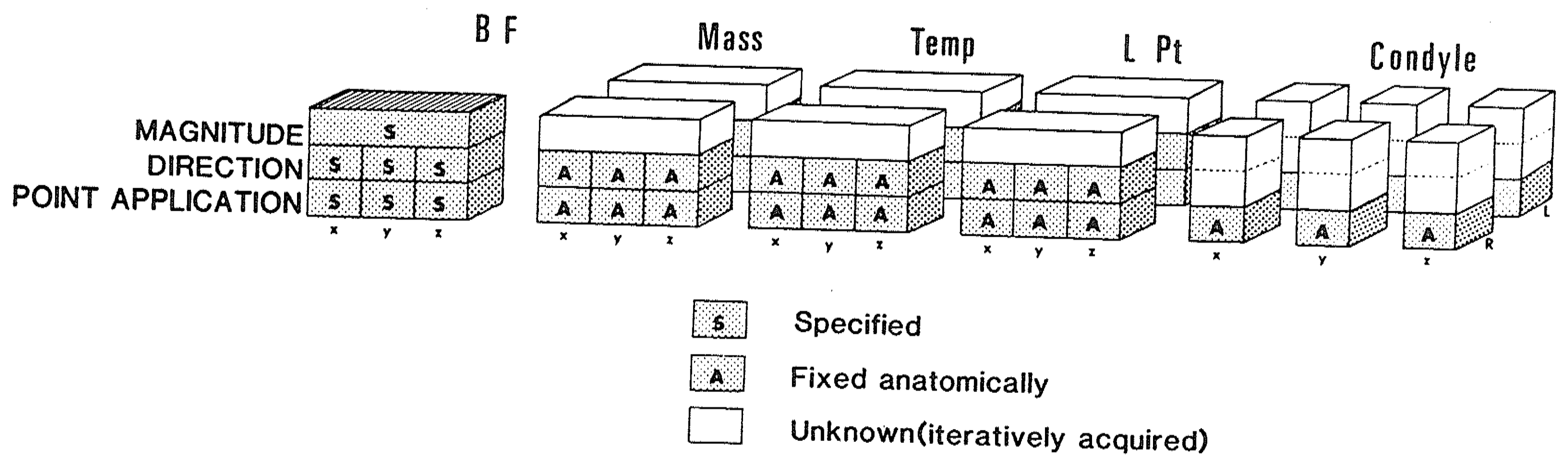


Figure 3.5 INFORMATION REQUIRED TO CALCULATE STATIC EQUILIBRIUM

(Modified from Smith (1984), with permission of the author) evaluation is proposed. The method has been tested on an osteological sample and applied to a clinical sample. The clinical and osteological samples involved, and a method of obtaining the desired three-dimensional measurements from radiographs, are described in the following sections.

1. Clinical Sample

Sixteen pre-orthodontic treatment patients from the University of Manitoba Graduate Orthodontic Clinic were chosen for investigation. The patients were North American Caucasians. Their ages ranged from thirteen years and nine months to twenty-six years and one month, with a mean age of 17 years and four months. There were equal numbers of males and females. All the patients were in good general health and were not known to be suffering from any chronic, and/or debilitating disease or disorder.

By orthodontic standards, these patients demonstrated malocclusions associated with some degree of gnathic, skeletal disharmony. In general, treatment of severe cases of "abnormal" skeletal, dentofacial patterns is most ideally addressed through orthognathic surgery in conjunction with orthodontic therapy. In fourteen of the sixteen cases used in this study, orthodontics combined with orthognathic surgery was the subsequently recommended treatment.

Form and function have been assumed to be related. By accepted orthodontic norms, it could be said that the clinical sample showed skeletal and dental malformations. Despite their so-called "malformations" however, "malfunction" to an obvious, health-compromising extent was not evident in these patients. This study was focussed upon the considerations of whether, and to what degree, functional compromises associated with the "abnormal" form demonstrated by the sample may have existed. The method described was aimed at investigating the relationship between orthodontic classification of "normal" and "abnormal" form, and the primary function of the masticatory system as related to the plane of occlusion.

The patients in this study were selected to represent extremes in terms of facial type. The patients were judged clinically to demonstrate dolicofacial or brachyfacial characteristics (Figure 3.6). These clinical classifications were verified cephalometrically by analysis of tracings made from lateral cephalometric radiographs. Figure 3.7 shows a typical lateral cephalometric tracing. The landmarks and reference planes pertinent to this method are indicated. The relative facial heights and the mandibular plane angles (MPA) for the selected individuals were quantified and compared to the normative ranges for these parameters given by the Manitoba Cephalometric Analysis* (Figure 3.8). In terms of anterior facial height proportions and mandibular plane inclinations relative to conventional reference planes (FH and SN), these patients

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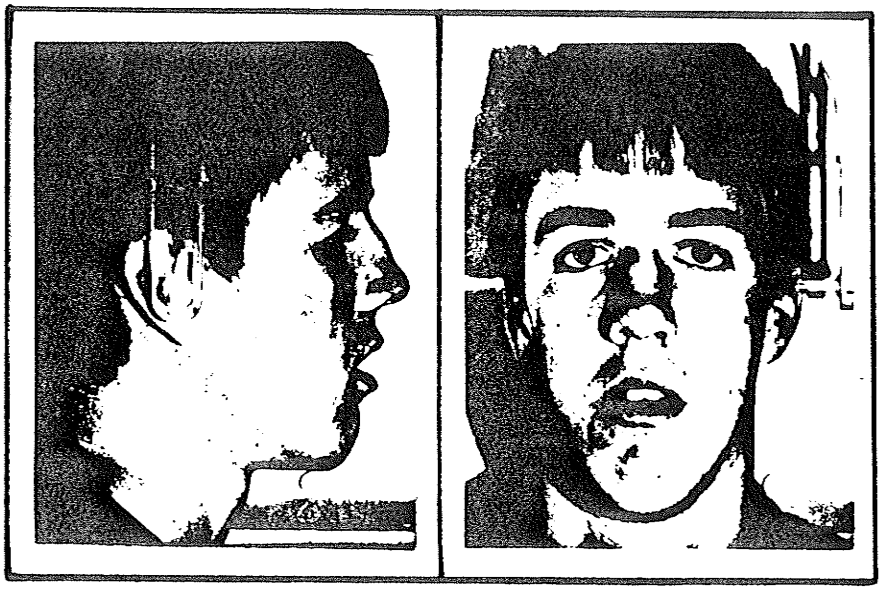
* The "Manitoba Analysis" is a set of standard values for commonly used cephalometric measurements based on a selected sample of Class I "normal" skeletal and dental pattern children of the city of Winnipeg, Manitoba, Canada (Beaton, 1973). These norms were felt to be appropriate for the clinical sample group described in this thesis.

LONG/STEEP FACIAL TYPE:
("Long Face Syndrome")



SHORT/FLAT FACIAL TYPE:
("Short Face Syndrome")

Figure 3.6 CLINICAL CHARACTERISTICS

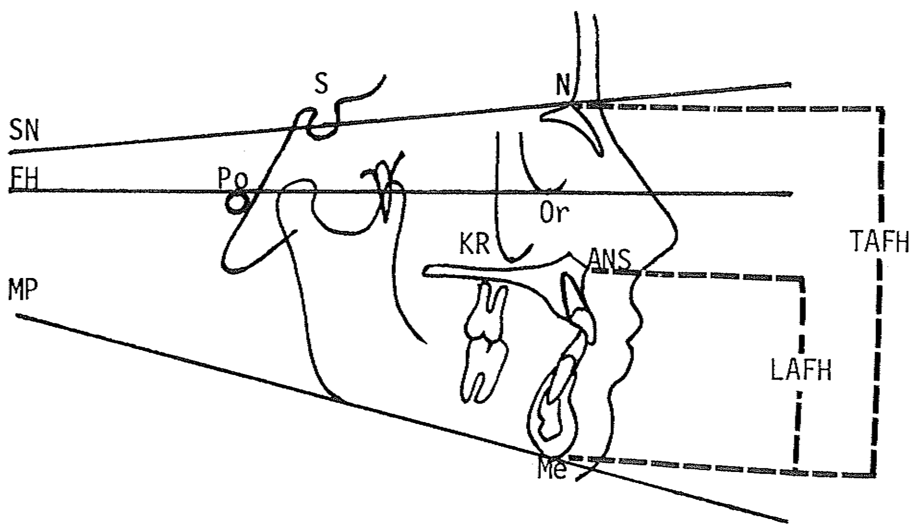


Figure 3.7 LATERAL CEPHALOMETRIC TRACING

CEPHALOMETRIC ANALYSIS
MANITOBA II (1984)

PATIENT'S NAME ______________________ BIRTHDATE ______________
Surname Given Name Initials — Day Month Year

DATE	D M Y	D M Y	D M Y	D M Y	D M Y
AGE	Y M	Y M	Y M	Y M	Y M
CODE					

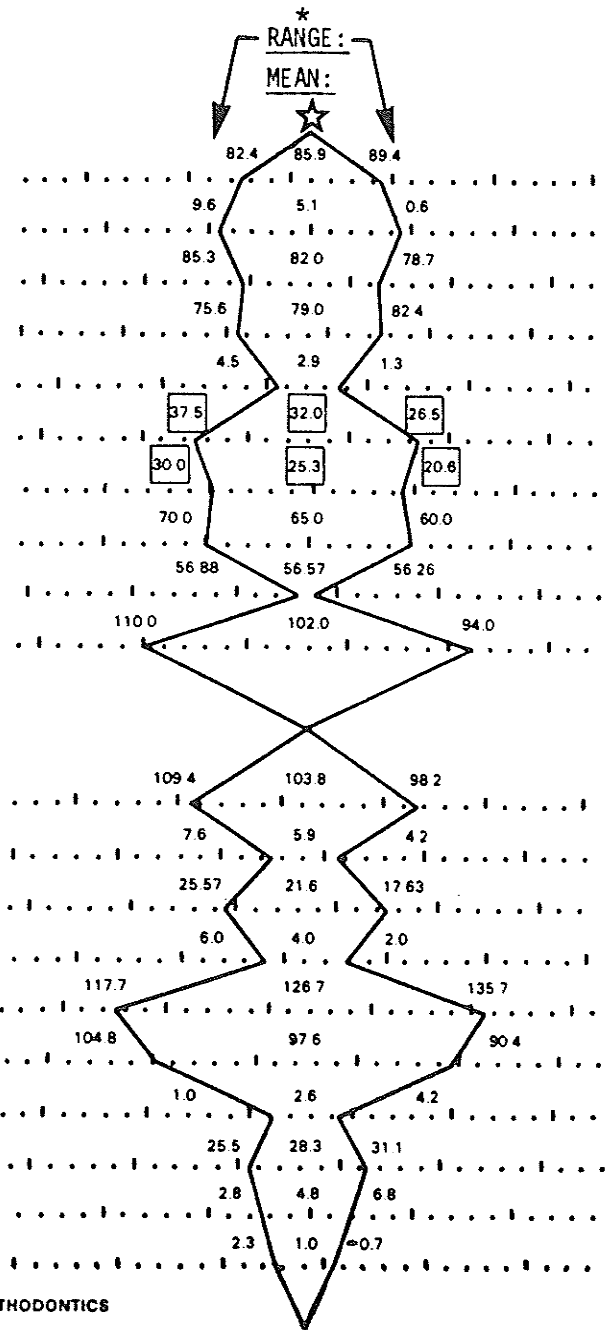
PRE-TREATMENT
DURING TREATMENT
POST TREATMENT
POST RETENTION
LONG RANGE RETENTION

SKELETAL PATTERN

NP-FH (°)					
NAP (°)					
SNA (°)					
SNB (°)					
ANB (°)					
1 MP-SN (°)					
2 MP-FH (°)					
ANS-Me (mm)					
ANS-Me / N-Me (%)					
NASO-LABIAL (°)					

DENTAL PATTERN

UI-SN (°)					
UI-AP (mm)					
UI-NA (°)					
UI-NA (mm)					
UI-LI (°)					
LI-MP (°)					
LI-AP (mm)					
LI-NB (°)					
LI-NB (mm)					
P-NB (mm)					



UNIVERSITY OF MANITOBA DEPARTMENT OF ORTHODONTICS

1 SNMPA
2 FHMPA

(*From Beaton, 1973)

Figure 3.8

were generally seen as being beyond the accepted ranges of "normal" (Table 3.1).

The use and relevance of the measurements of facial height proportions and mandibular plane inclination have been referred to in Chapters 1 and 2. More specific definitions are given in the following paragraphs. All descriptions are made in reference to a lateral-view cephalometric tracing.

Anterior facial height proportions were expressed by the lower anterior face height (LAFH) as a percentage of the total anterior face height (TAFH). The TAFH, as conventionally measured, was the distance between the points Nasion (N, the junction of the frontonasal suture with the skeletal profile outline of the bridge of the nose) and Menton (Me, the lowest point on the symphyseal outline of the chin). The LAFH was measured between Me and Anterior Nasal Spine (ANS).

The mandibular plane inclinations were measured by the angle formed between the mandibular plane and the conventional reference planes Sella-Nasion (SNMPA), and Frankfort horizontal (FHMPA). The mandibular plane (MP) was a line drawn tangentially to the posterior portion of the lower border of the mandible, and to the symphyseal curve (through Me). SN plane was drawn as a line joining N with the centre of sella turcica, the hypophyseal fossa in the cranial base of the skull. FH plane was drawn from Orbitale (Or, the lowest point of the bony orbit) to Porion (Po, the top of the shadow of the cephalostat ear rod in the external

Table 3-1 - THE UNIVERSITY OF MANITOBA CLINICAL SAMPLE*

Patient	Sex	Age (years-months)	LAFH/TAFH (%)	SNMPA (degrees)	FHMPA (degrees)
Long/Steep Group:					
J.B.	M	13-9	57.0	45.5	34.5
J.W.	M	14-0	56.2	38.0	31.5
K.M.	F	14-4	60.8	48.0	41.5
P.A.	F	15-10	58.9	37.0	34.0
D.K.	M	17-3	57.8	38.5	37.5
B.P.	F	17-4	63.6	56.0	53.5
J.Z.	M	17-5	62.4	53.0	48.0
T.K.	F	20-0	60.3	44.0	36.5

Mean age of long/steep group: 16 years - 3 months

Patient	Sex	Age (years-months)	LAFH/TAFH (%)	SNMPA (degrees)	FHMPA (degrees)
Short/Flat Group:					
S.E.	M	15-0	52.2	22.0	14.0
D.H.	M	15-9	53.4	25.0	18.0
C.S.	F	15-9	51.8	21.5	12.0
T.W.	F	17-0	55.1	26.0	19.5
L.P.	F	18-8	54.8	17.0	12.0
P.D.	M	19-2	56.6	23.0	18.0
A.L.	F	20-1	54.8	22.0	11.5
D.M.	M	26-1	53.8	23.0	16.5

Mean age of short/flat group: 18 years - 5 months

OVERALL MEAN AGE OF CLINICAL SAMPLE: 17 years - 4 months

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* Where: F = female M = male
LAFH = Lower anterior facial height
TAFH = Total anterior facial height
SNMPA = Sella-Nasion - Mandibular plane angle
FHMPA = Frankfort horizontal - Mandibular plane angle

auditory meatus). Since Or and Po are both bilateral landmarks, the points representing them were averaged over the right and left sides.

LAFH/TAFH, SNMPA, and FHMPA measurements clearly separated the long LAFH/steep MPA (long/steep) group from the short LAFH/flat MPA (short/flat) group. As well, superimpositions of lateral cephalometric tracings on both FH and SN planes demonstrated two distinctly different facial types by normal standards of assessment (Figure 3.9 shows superimpositions on SN). This conventional distinction between the two groups of people examined was tested with respect to function, by investigating the mechanical potential of their respective masticatory systems.

The geometric anatomical relationships between the condylar heads, the origins and insertions of the masseter, temporalis, and lateral pterygoid muscles, and the tooth row for each of the patients were obtained from tracings of standard orthodontic lateral and posteroanterior (PA) cephalometric radiographs. These radiographs were part of the initial records made at the University of Manitoba and hence were available for study. The derived geometries were used in the model and the condylar load and muscle activity patterns were calculated for each of the eight individuals in the long/steep group and each of the eight individuals in the short/flat group.

The cephalometric radiographs were obtained in the Oral Diagnosis/Radiology Clinic, Department of Stomatology,

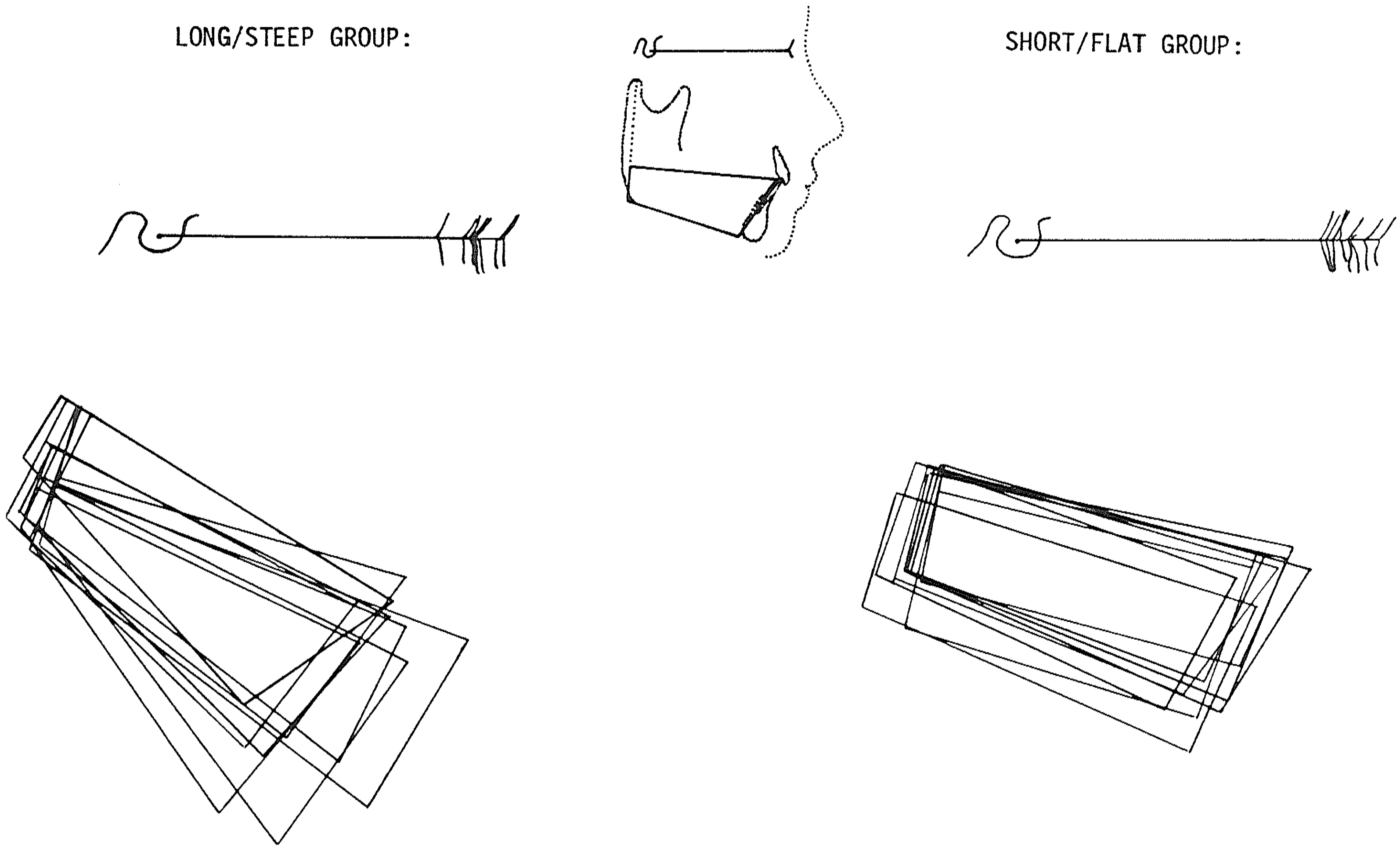

Figure 3.9 LATERAL CEPHALOMETRIC SUPERIMPOSITIONS ON SN

Faculty of Dentistry, University of Manitoba*. A Taylor** cephalostat was used in a Picker*** radiographic unit, where the focal spot-midsagittal plane distance was 152.4 centimeters, and the film-midsagittal plane distance was 15 centimeters. As found in most modern cephalometric radiographic units (Moyers, 1979), the x-ray source was fixed, so that after the lateral view was exposed, the cephalostat was rotated ninety degrees and the patient was repositioned for the PA exposure. The radiographs were made using Kodak X-OMAT RP (Registered Trademark) film with regular speed screens. For the lateral cephalometric views, the machine settings were 10 mA and 85 kVp for an exposure of 7/10 second. For the PA views, the machine settings were 10 mA and 90 kVp for an exposure of one second. An upright stance and forward gaze with the teeth in full-occlusion and the lips relaxed, was the standard position for all of the radiographs made of the patients involved in this study.

2. Osteological Sample

In order to determine whether the geometric relationships of the teeth, temporomandibular joints, and the muscles of mastication could be accurately derived from

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Winnipeg, Manitoba, Canada R3E 0W3

** N. Taylor Engineering Ltd.,
Parkstone-Dorset, England

*** Picker X-ray Engineering Ltd.,
Winnipeg, Manitoba

cephalometric radiographs, data from a human osteological sample were obtained. The sample consisted of ten human skulls selected from the Hamann-Todd (H-T) Osteological Collection. This unique collection is housed in the Department of Physical Anthropology, at the Cleveland Museum of Natural History.* The Hamann-Todd Collection represents an exceptionally well-documented and catalogued assembly of autopsied skeletal remains. Relatively complete records of over two thousand eight hundred macerated cadavers, which were accumulated over the latter part of the nineteenth century and first half of this century, are now stored in the museum. The accompanying autopsy and pathology reports have included as much detailed information as possible. Where available, records from medical and civic authorities have been included to assist the accurate recording of each individual's chronological and maturational age, sex, ethnicity, provenience, health history, and cause of death. Heights and body weights of the cadavers, as well as photographs in some cases, helped to give further indication of general body constitution.

Ten adult skulls with mandibles and relatively intact natural dentitions were selected. These specimens were believed to be in relatively good general health at the time of their deaths. Specimens whose records showed evidence of long-standing chronic and/or osteologically degenerative

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* The Cleveland Museum of Natural History,
Wade Oval, University Circle,
Cleveland, Ohio, U.S.A. 44106

processes were not included in the sample. The ten specimens are described with respect to age, sex, ethnic origin, and cause of death, in the Table 3-2.

The photographic data collected from the skeletal sample was used to test a cephalometric radiographic technique for data collection. This was accomplished by comparing the anatomic measurements obtained from the skulls with the radiographic anatomic measurements obtained from standardized cephalometric radiographs of the same skulls. The ten osteologic specimens were also selected to represent extremes in terms of facial type, and could be divided into two groups, with five skulls showing long face heights and steep mandibular plane inclinations, and five skulls showing short face heights and flat mandibular plane inclinations.

i. Photographic Records

Geometric anatomic data suitable for use in the model was obtained from the skulls using a standardized photographic technique developed by Nickel, McLachlan and Smith (Nickel, 1987). This technique facilitated the measurement of specific points relative to a defined orthogonal axis system, and provided a means of transporting and storing the skeletal information as a resource material.

The three-dimensional relationships of each skull and mandible have been recorded through a series of nine photographs. The photographs were made in standardized

Table 3-2 - THE HAMMAN-TODD OSTEOLOGICAL SAMPLE

Hamman-Todd Number	Age (years)	Sex	Ethnicity	Cause of Death
T0174	40*	Male	Caucasian	Lobar Pneumonia
T0171	39*	Male	Black	Lobar Pneumonia
T0333	25*	Male	Black	Hit by Train
T0255	48	Male	Caucasian	Gangrene of Foot
T0509	52*	Male	Caucasian	Nephritis
T0449	40*	Male	Caucasian	Pneumonia
T0238	30	Male	Caucasian	Pulmonary T.B.**
T0326	30	Male	Black	Lobar Pneumonia
T0484	30	Male	Caucasian	Pulmonary T.B.**
T0463	54	Male	Caucasian	Myocardial Infarct

* Estimated age at time of death
** Tuberculosis

views based on three anatomic planes: the sagittal, the frontal, and the basal planes.

In preparation for photographing, the selected skulls were inspected carefully and the areas of the origins and insertions of the three muscle pairs were outlined with coloured Letraline (Registered Trademark) 1.59 millimeter, matte-finish, drafting tape. The main portions of the muscles involved in elevating the jaw to a centric, isometric, bite position were considered. The areas of muscle attachment were identified by the observed bony scarring, guided by the anatomical descriptions of Sicher and DuBrul (1975). On the basis of assumed gross morphologic symmetry, only one side, the right or the left, was prepared and photographed. Inter-individual and intra-individual variability was noted in the location and the degree of bony scarring. The side in which the bony scarring best delineated the outline of the muscle attachment was chosen in cases where a right-left difference existed. The muscle attachments of the masseter, temporalis, and lateral pterygoid muscles, as used in this study, are described in the paragraphs to follow.

The action of the superficial portion of the masseter muscle has been said to be involved during isometric biting from a centred, minimally-opened, jaw position (Sicher and DuBrul, 1975). Generally, the origin of the more superficial portion of the masseter muscle, was represented in this study by an area running along the inferior border and lateral cortex of the zygomatic arch (Figures 3.11 and

3.17). This area has been defined as extending posteriorly to the region of the zygomaticotemporal suture (Sicher and DuBrul, 1975) and anteriorly on to the zygomaticomaxillary process. The insertion of the masseter muscle was marked in the area of the angle of the mandible extending anteriorly towards the level of the lower second molar tooth, and on the lateral cortical surface of the inferior portion of the ramus (Figure 3.10).

The origin of the temporalis muscle was delineated according to Sicher and DuBrul (1975), in that it followed the inferior temporal line and thereby extended over the temporal, parietal, sphenoid (greater wing) and frontal bones on the lateral part of the skull (Figure 3.11). The insertion of the temporalis muscle was outlined on the medial and lateral cortical surfaces of the coronoid process. The bony scarring of the insertion was seen to extend anteriorly and inferiorly towards the posterior end of the alveolar process of the mandible, lateral and medial to the retromolar fossa (Figures 3.10, 3.13, and 3.16).

The outline of the origin of the lateral pterygoid muscle included the regions occupied by the inferior and superior heads of the muscle (Figure 3.17). Bony scarring was observed on the lateral cortical surface of the lateral pterygoid plate of the sphenoid bone, representing the origin of the inferior head (Figure 3.17). The scarring extended superiorly onto the infratemporal surface of the greater wing of the sphenoid. This area, medial to the

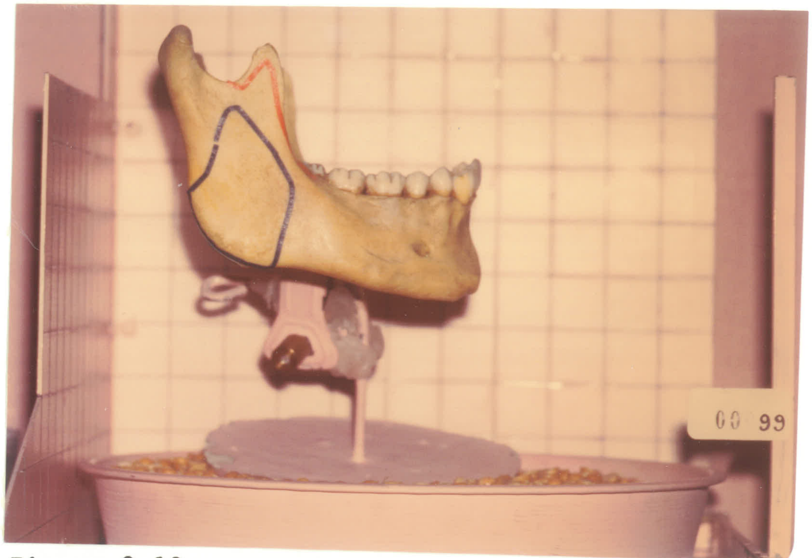

Figure 3.10 SAGITTAL PHOTOGRAPH OF MANDIBLE

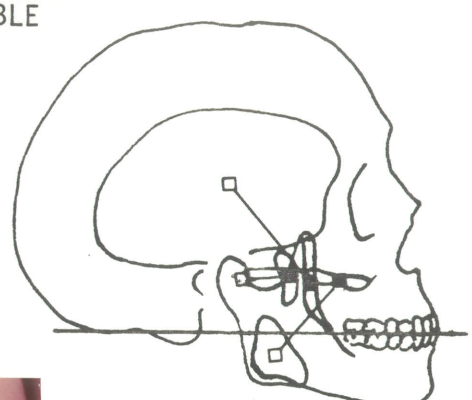

Figure 3.12 COMPOSITE SAGITTAL TRACING

■ MUSCLE ORIGIN

□ MUSCLE INSERTION

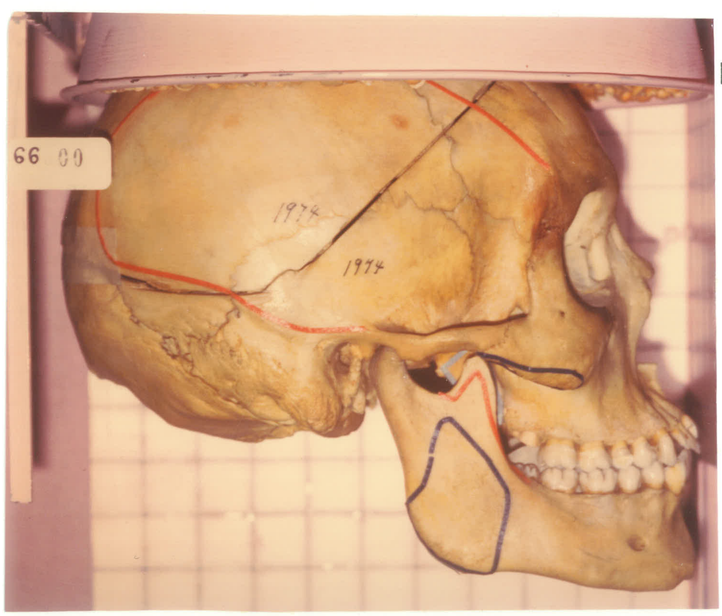

Figure 3.11 SAGITTAL PHOTOGRAPH OF SKULL WITH MANDIBLE

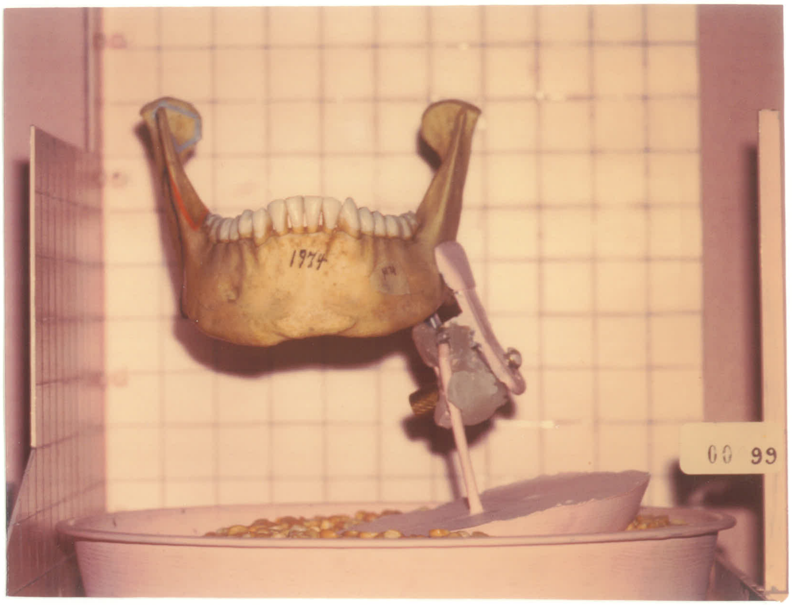

Figure 3.13 FRONTAL PHOTOGRAPH OF MANDIBLE

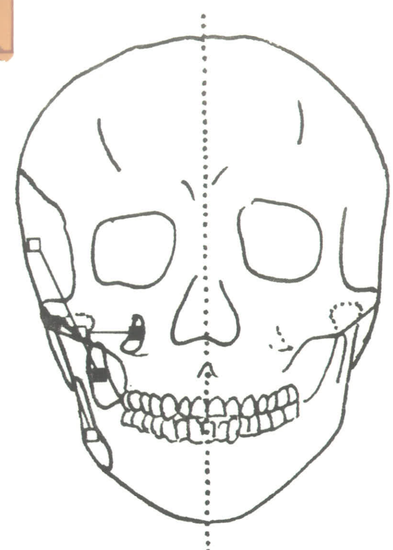

Figure 3.15 COMPOSITE FRONTAL TRACING

■ MUSCLE ORIGIN

□ MUSCLE INSERTION

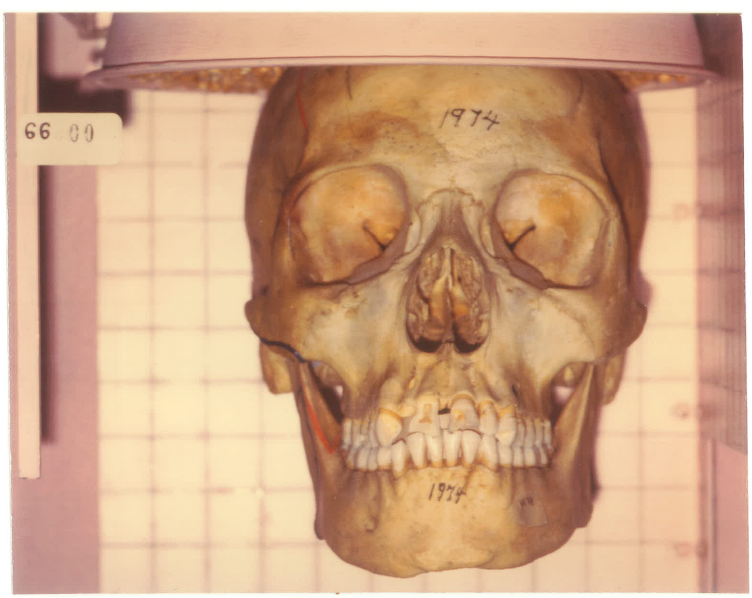

Figure 3.14 FRONTAL PHOTOGRAPH OF SKULL WITH MANDIBLE

Figure 3.16 OCCLUSAL PHOTOGRAPH OF MANDIBLE

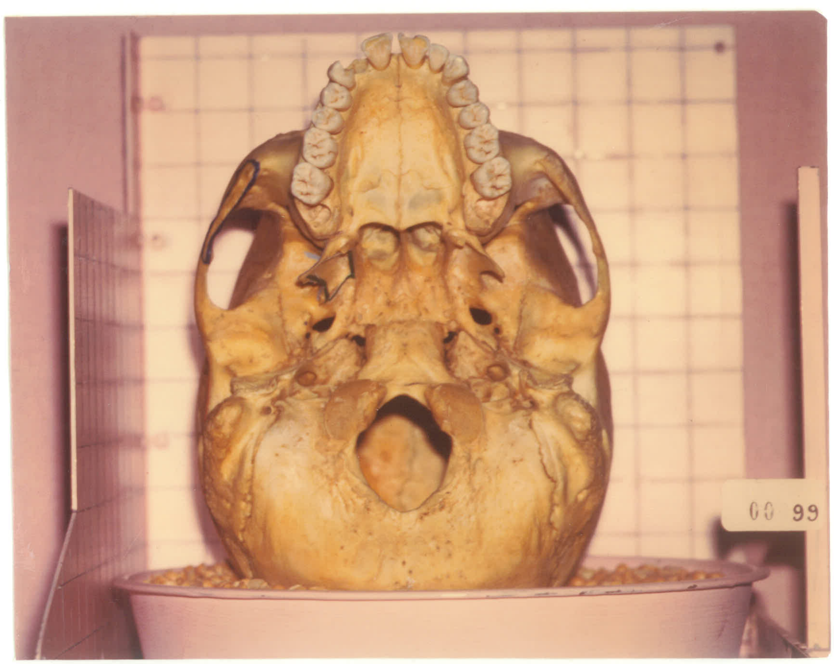

Figure 3.17 BASAL PHOTOGRAPH OF SKULL

infratemporal crest, which formed the roof of the temporal fossa, represented the superior head. The insertion of the lateral pterygoid muscle was outlined by the muscle scarring evident in the fovea of the condylar neck (Figure 3.16).

The photographs were made with the prepared skulls and/or mandibles positioned within a specially constructed framework (Figure 3.18). This framework had a set and identifiable focal plane, located at the most anterior limit of the framework with respect to the camera. This focal plane was marked by a metal rod measuring 149 millimeters in length, which was used as a guide to the positioning of the specimens. The metal rod was included in the photographs, to one side of the specimen. Inclusion of this rod permitted the obtained photographic images to be scaled to size. It also allowed perspective errors to be calculated for measurements of coordinates located behind the focal plane.

The specimens themselves were supported by a dry, large-particle medium (split yellow peas) in a metal pan attached to the framework. The set-up allowed sliding of the pan towards and away from the camera in the horizontal plane. The position of the pan within the framework could thus be adjusted with respect to the focal plane. For the photographs made of the skull with the mandible, the position of full-occlusal articulation of the teeth was approximated, judging from the occlusal facets and patterns of dental attrition, and the mandible was secured to the skull in that position with masking tape. Where support

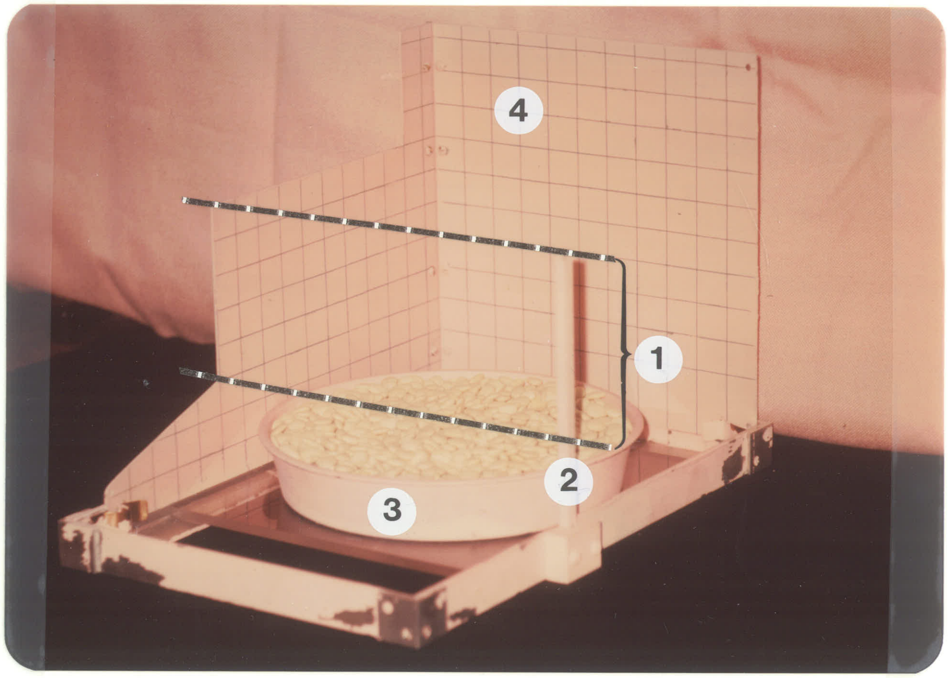

Figure 3.18 PHOTOGRAPHIC FRAMEWORK

1. Photographic focal plane
2. Metal rod (length = 149 millimeters)
3. Pan with support medium
4. Backdrop with grid for specimen orientation

(Modified from Nickel (1987), with permission of the author) from the masking tape alone would interfere with visibility of important anatomical structures, manual support was provided by an assistant. For the photographs of the mandible alone, a holding device was used to suspend the jaw bone above the support medium so that the entire mandible was visible in the photograph.

Three sagittal plane views of each specimen were recorded. These showed the skull alone, the mandible alone (Figure 3.10), and the skull and the mandible together (Figure 3.11). The sagittal view photographs were made with the specimen adjusted to have the sagittal plane parallel to the focal plane and the occlusal plane horizontal. For the sagittal views of the skull alone and with the mandible, the position of the specimen was adjusted to have the parietal eminence intersecting the focal plane. For the sagittal view of the mandible only, the ipsilateral condyle was positioned to intersect the focal plane.

Three frontal plane views were recorded. These showed the skull alone, the mandible alone (Figure 3.13), and the skull and the mandible together (Figure 3.14). The frontal view photographs were made with the specimen adjusted to have the frontal plane parallel to the focal plane and the occlusal plane horizontal. In these views the most anterior portion of the specimen was positioned to intersect the focal plane.

Two basal aspect photographs of each specimen were made, one with the skull alone (Figure 3.16) and the other with the mandible articulated. In these views, the occlusal plane was positioned parallel to the focal plane, and the most proximal portions of the skull and the mandible in this position, were set to intersect the focal plane.

An occlusal view of the mandible (Figure 3.17) completed the set of nine pictures made for each specimen. The occlusal plane was oriented parallel to the focal plane for this photograph, and the most superior aspects of the condyles, or in some cases, the coronoid processes, were positioned to intersect the focal plane.

A Minolta (Registered Trademark) 35 millimeter, single lens reflex camera was used on a fixed tripod, with the camera lens-focal plane set at a distance of 100 centimeters. The camera was set at f-8, and the bellows at position 9, on the given scales. The Kodak (Registered Trademark) EPY 135, ASA 50 film employed was processed and developed by a commercial photographic laboratory.

ii. Cephalometric Records

The same ten adult specimens used in the photographic technique were radiographed in the standard orthodontic lateral and PA cephalometric views. Prior to x-ray exposure, radio-opaque markers were affixed to the skulls. These markers assisted the identification of the muscle attachment centroids for the three muscle pairs on the radiographs obtained. The centroid of a muscle attachment has been defined, for the purposes of this study, as the investigator's best approximation of the midpoint of the muscle attachment, which would be intersected by a line demonstrating the main direction of muscle pull in a centric, isometric bite position. This definition has taken into consideration the muscle bulk as well as attachment area. It therefore was not a mathematical centroid calculated strictly from the two-dimensional outline of the muscle attachment.

Small pieces of lead foil were secured with transparent tape to the estimated centroid positions of the origins of the masseter, temporalis, and lateral pterygoid muscles, and the insertion of the temporalis muscle. To mark the insertions of the masseter and lateral pterygoid muscles, 1.0 millimeter diameter, dead-soft, solder wire, secured by tape, was used to mark the approximate length of the major extent of the area. With the radio-opaque markers in place, the mandible and cranial portion of each specimen were articulated according to the dentition, as in the photographic technique, and secured in this position with masking tape.

The set-up used to obtain the cephalometric radiographs of the osteological sample was provided by the School of Dentistry, Case Western Reserve University.* The specimens were transported from the museum to the Bolton-Brush Study Room in the Department of Orthodontics at Case Western Reserve University, for radiographing. The Bolton-Brush cephalometric x-ray unit utilizes two x-ray sources and two film holders so that the subject, or specimen in this case,

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* Case Western Reserve University, School of Dentistry, 2123 Abington Road, Cleveland, Ohio, U.S.A. 44106

did not need to be moved between the lateral and PA exposures. The cephalostat therefore did not rotate. This unit was modelled after that used for the original Broadbent-Bolton cephalometric study, first described in 1931. An orbitale pointer helped to locate Frankfort horizontal plane in the specimen in order to more accurately orient this plane parallel to the floor. The ear rods of the cephalostat were positioned and secured in the external auditory meati of the skull, with the nasion locator helping to provide additional support. The specimens were thus suspended in the cephalostat and exposed for both cephalometric views. The advantage of this set-up was that more precise three-dimensional interpretations were possible than would be the case if the subject or skull was repositioned for the second exposure.

3. Methods of Tracing Records

i. Osteological Photographic Records

The standardized photographic transparencies of the selected Hamann-Todd specimens were projected onto a flat surface, and the images were adjusted to a real-life scale for tracing. This was accomplished by adjusting the image so that the projection of the metal reference was 149 millimeters long, thus matching the actual measured length of the rod. By superimposing the nine standardized views, "life-sized" tracings were made of the lateral and frontal aspects of each specimen (Figures 3.12 and 3.15). The desired three-dimensional geometric coordinates were measured from these two composite tracings, the x-coordinates and y-coordinates being obtained from the lateral aspect tracing and the z-coordinates being obtained from the frontal aspect tracing. The coordinate axis system was defined in this study, to be centred at the midpoint of the intercondylar axis, where the intercondylar axis was the line perpendicular to the midsagittal plane of the specimen, that intersected the most anterosuperior, central point of each of the condyles. The x-axis and the z-axis were defined as lines lying in a horizontal plane, parallel to the occlusal plane of the specimen, running anteroposterioly and mediolaterally, respectively. The y-axis was therefore defined as the vertical axis, which ran superoinferiorly, perpendicular to the occlusal plane (Figure 3.2).

All tracings were made in a systematic fashion. In order to minimize perspective errors, the view which showed the area of interest closest to the focal plane was used whenever possible, to draw the area in the tracing. The method employed to construct the composite lateral and frontal tracings from the photographic slide series for a given specimen, will now be outlined in detail.

The lateral aspect tracing was based mainly on the sagittal views of the skull and mandible alone and together. From the projection of the transparency of the lateral view of the mandible, the occlusal plane was established in relation to the condyle, the coronoid process, the ramus, and the angle of the mandible (Figure 3.10). The anterior and posterior tooth positions (CA and 2m) were marked along the line representing occlusal plane in the tracing. From this lateral view of the mandible transparency, the outline of the entire insertion of the masseter muscle and what could be seen of the temporalis muscle origin, as delineated by the drafting tape, were traced. The most anterosuperior point on the profile of the condyle was marked, and where visible, any portion of the markings of the lateral pterygoid muscle insertion were also traced.

The tracing was then superimposed by the projection of the lateral view skull-with-mandible transparency (Figure 3.11). The occlusal plane was lined up as in the first transparency of the mandible alone, and the best-fit of the condyle, the coronoid process, the ramus and the angle of the mandible was established. Any differences seen in the anteroposterior positioning of the teeth reflected discrepancies due to perspective and/or technique errors. The outlines of the masseter muscle and temporalis muscle origins were added to the tracing, as was any portion of the lateral pterygoid muscle origin, visible through the semilunar notch. Additional portions of the outline of the lateral pterygoid muscle origin were obtained from the superimposition of the lateral view of the skull alone.

Both basal views, and the frontal and occlusal views of the mandible were studied carefully in order to appreciate the extension of the muscle attachments not seen in the lateral view projections. In particular, the origin of the superior head of the lateral pterygoid muscle which extended on to the roof of the infratemporal fossa, the lateral extension of the temporalis muscle insertion on the coronoid process, and the fovea area of the condylar neck, were examined and taken into account. This aided the selection of muscle "centroids" for measurement from the lateral view tracing. Muscle "centroid," as used here, was defined in the previous section. From the composite lateral view tracing, the x-coordinates and the y-coordinates of the condylar head, the tooth positions, and the origins and the insertions of the three muscle pairs were derived.

The midplane of the frontal aspect tracing was established from the frontal skull-with-mandible projection by a best-fit line through bilateral cranial and mandibular structures (Figure 3.14). The teeth and some of the midplane structures were traced for superimposition purposes. The mediolateral positions of the temporalis and masseter muscle origins were located through the frontal view as well as through the basal view of the skull alone. The insertions of the masseter and temporalis muscles were also sketched in from this view, and then checked by comparison with the frontal view of the mandible alone (Figure 3.13). The basal view of the skull-with-mandible also helped to locate the masseter muscle insertion.

The mediolateral position of the distobuccal cusp of the second mandibular molar and the cusp tip of the mandibular cuspid were marked on the tracing. These were derived from the frontal view transparency projection of the mandible alone, or from the occlusal view of the mandible

(Figures 3.13 and 3.16). From these projections, the mediolateral positions of the centre of the condyle and the centroid of the lateral pterygoid muscle insertion were also marked.

A knowledge of the lateral aspect positions of the muscle centroids aided the mediolateral location of centroids of the masseter and temporalis muscle insertions and origins in the frontal aspect. The mediolateral position of the centroid of the lateral pterygoid muscle origin was derived from the basal view of the skull (Figure 3.17) superimposed along the midsagittal plane of the tracing.

The z-coordinates were measured from the frontal aspect tracing as perpendicular distances from the midsagittal plane (Figure 3.15). The required data set describing the geometric anatomical relations of the condyles, the teeth, and the three muscle pairs was, in this way, complete and ready to be tested in the model.

ii. Osteological Cephalometric Records

Systematic tracings, including conventional cephalometric landmarks (as used in the Manitoba Cephalometric Analysis, see Figure 3.8) were made from the lateral and PA radiographs of the Hamann-Todd specimens. Both the right and left radiographic images were drawn for bilateral structures. In the case of the condyles, the right and left lateral view images were averaged to mark the most anterosuperior point on the radiographic profile of the condyles.

From the lateral cephalometric radiograph, the occlusal plane was drawn in. The anterior and posterior tooth positions (CA and 2m) were labelled along the line representing the occlusal plane. The images of the radio-opaque markers were also traced and their location with respect to cephalometric landmarks and structures were studied carefully.

The centroids of the masseter and lateral pterygoid muscle insertions, and the temporalis muscle origin and insertion, were given by the centre of the metallic marker. For the masseter and lateral pterygoid muscle origins, the centroids were chosen by the investigator, guided by the radio-opaque lines marking the extensions of these muscle origins. This was assisted by the experience gained from the direct and indirect (via the photographic technique) examination of osteological specimens. A point on the radio-opaque marker just posterior to the cephalometric landmark, "Key Ridge," near its most inferior point, was generally selected to represent the centroid of the masseter muscle origin (Figure 3.7). Key ridge (KR), is a bilateral structure seen in the lateral view, as the radiographic image of the posterior edge of the frontal process of the zygomatic bone. For the centroid of the lateral pterygoid muscle origin, the approximate centre of the radio-opaque line marking the muscle attachment was selected.

A tracing was also made of the PA cephalometric radiograph. The position of the midplane was established, represented in the tracing by a best-fit line through midplane structures, and reflecting as closely as possible, symmetry of bilateral structures. The skeletal radiographic images were studied with respect to the positions of the applied radio-opaque markers. The centres of the lead foil images were marked as the centroids to the muscle attachments of the temporalis muscle and the insertions of the masseter and lateral pterygoid muscles. The points chosen to denote the centroids of the origins of the masseter and lateral ptergoid muscles, in this view, were the points of most convexity and concavity respectively, along the lines marking the extension of these muscle attachments.

The mediolateral centre of the condyle and the positions of the distobuccal cusp of the mandibular second molar and the cusp tip of the mandibular cuspid tooth on one side, were also marked in the tracing. The geometric data for use in the model could thus be derived from the composite tracing of the cephalometric radiographs in a fashion of measurement similar to that used in the photographic technique. The x-coordinates and y-coordinates were measured from the lateral view tracings of cephalometric radiographs and the z-coordinates were measured from the PA view tracings of cephalometric radiographs.

iii. Clinical Cephalometric Records

The tracings of the lateral and PA cephalometric radiographs of the clinical subjects were made in a manner identical to the tracings made of cephalometric radiographs of the osteological sample. There were of course, no artificial markers to indicate the centroids of the muscle attachments in the clinical sample. The locating of the centroids of the masseter, temporalis, and lateral pterygoid muscle attachments was done in a systematic and consistent manner, and was dependent upon knowledge of the anatomy, particularly with respect to cephalometric radiological interpretation, and experience in tracing.

IV ERROR CONSIDERATIONS

1. <u>Photographic Technique Errors</u>

One of the main errors associated with the measurement of a two-dimensional photographic representation of a three-dimensional object was that of perspective. Correction for such perspective errors addressed an elemental problem of parallax. Investigations aimed at establishing correction factors for the described photographic technique have been carried out by Nickel (1987). Photographs made of a complex, rectangular, three-dimensional object of known dimensions were projected and traced. The projection was scaled such that the front of the object, which was positioned to intersect the focal plane, was traced to "life-size." By comparing the traced dimensions of parts of the object located behind the focal plane with the known dimensions of those parts of the object, a correction factor was calculated.

A perspective error equation based on this correction factor was thus established:

$$Ma = Mt\ (1 + D/1000)$$

where Ma = the corrected measurement or "actual" measurement of the coordinate (x,y, or z);
Mt = the measurement of the coordinate obtained from the tracing;
and D = the distance of the coordinate behind the focal plane of the coordinate;
where Ma, Mt, and D are given in millimeters.

The value of 1000 in the denominator of the error factor represents the set distance between the lens of the camera and the focal plane, and is also expressed in millimeter units.

The distance D, behind the focal plane was determined from the photographic views and thus was subject to some error in itself, but this error was of a relatively small magnitude. Resolution of the error in the measurement of distance D, could be addressed through an iterative approach but, to a first approximation of perspective error, the distance D as measured directly from the tracing, was thought to suffice for the purpose of this study.

The corrected measurements of interest with respect to the different photographic aspects were as follows: for the lateral view photographic tracings, Ma(x) and Ma(y); for the frontal view photographic tracings, Ma(y) and Ma(z); and for the basal and occlusal photographic tracings, Ma(x) and Ma(z). The view used was one which allowed a particular tracing measurement Mt to be made, and where distance D was smallest. This helped to minimize the difference between Ma and Mt due to perspective.

For any of the specimens photographed and measured by the technique described, the largest relative error in any measurement made directly from the tracing without regard for perspective, was ten percent of the distance behind the focal plane of the measured part of the specimen. The largest errors in measuring directly from the tracing therefore occurred when the distance D was largest for the view in which the coordinate to be measured was located as close to the focal plane as possible. The specimen associated with the largest perspective error was found to be H-T Specimen #75. For this specimen, the measurement of the z-coordinate of the origin of the temporalis muscle was associated with a D-value of 83 millimeters in the view showing the muscle origin as close to the focal plane as possible. The difference between Ma and Mt for this coordinate was therefore 8.3 percent of the measured Mt.

The importance of perspective error considerations was investigated by using the model. All of the measured coordinates for H-T Specimen #75 were corrected for perspective. The model was then run based on this perspective-corrected data to compare the results with those based on the unaltered data. The specified biting conditions for this perspective error investigation were: a bite force of 100 units in magnitude, applied to the tooth row in a vertical direction at four positions anteroposteriorly, along the right-hand half of the tooth row.

The comparison of the corrected versus the unaltered geometric descriptions of the H-T Specimen #75 as expressed by the model, for the specified conditions, showed very little difference between the predicted results in terms of the magnitudes and directions of loads on the condyles. Any difference in the condylar load magnitude or the muscle force magnitude was expressed as a percentage of the applied bite force. The average difference in the resultant load on either the right or left condyles over the four anteroposterior positions was 2.9 percent. The range of differences for the resultant condylar loads was 0.8 percent to 5.1 percent. Average values for the differences between the x-axis components and y-axis components of the condylar loads for the unaltered versus the corrected situations were 1.4 percent and 2.6 percent respectively. The maximum difference between the two data sets, in their predicted force magnitudes for the muscles and the condyles, was 5.4 percent of the applied bite force. This maximum difference occurred in the predicted muscle force value for the masseter. The average difference in the direction of the load acting on the condyle was 0.4 degrees, with a range of 0.1 degrees to 0.6 degrees. These differences in the predictions made by the model, represented the maximum amounts of error involved in calculating the magnitude and direction of the minimum condylar loads and muscle forces required to attain these, when unaltered measurements, obtained directly from the tracing were used. For the purposes of this study, it was felt that the amount of error associated with the predictions from the unaltered geometries was small enough to permit the use of the traced measurements without perspective-correction.

There were other errors inherent in the photographic technique. These errors were associated primarily with the set-up of the technique itself, and with the limitations of the operator. In order to obtain the photographs as desired, the positioning of the specimens within the framework was very important in terms of proper orientation. The specimens were not perfectly symmetrical, and hence some degree of operator judgement was required in determining the best position of the skull and/or mandible for photographing. Such errors, which occurred with the obtaining of the photographs, tended to be unpredictable. Informal assessment of changes in dimension due to operator judgement, indicated that such errors would be small when compared with other errors.

Assuming therefore, that the errors associated with the photographic transparencies were relatively small, attention was focussed toward the operator errors which were incurred through the photographic technique. Operator-related errors occurred in the projection of the photographic images, in the locating of the anatomical landmarks, and in the tracing and measuring of these landmarks. Errors in the projection of a photographic image would largely have entailed magnification and/or distortion errors. As long as the distortion errors were kept to a minimum, projection errors could be considered negligible, since any magnification or dimunition of the size of the specimen would not affect the relative geometric relationships within it, and therefore would not affect the predictions of the model. Errors in the actual tracing of the visible landmarks and anatomic parts, and the measurement of selected points, were non-systematic and relatively small. The largest operator error was associated with the establishment of occlusal plane and with the selection of muscle centroids for the establishment of representative muscle vectors. Repeated tracings of one specimen were carried out in order to characterize the operator error associated with the selection of data points for measurement from the photographic tracings. An analysis of the measurements for H-T Specimen #75 was done in three separate test trials, in which the described technique was applied by the same operator. In order to minimize the influence of the operator's memory, and encourage impartial and unbiased but systematic tracing, procedures were carried out using the photographic transparency series for the specimen in three different orientations: conventionally (as photographed), rotated by 90 degrees, and where the mirror-image projection was rotated by 180 degrees.

The individual measurements from the three test trials were compared. Relative measurements of the condylar position and the tooth row showed a maximum discrepancy of 5.5 millimeters overall (for the measurement of central anterior position, in this case), while the largest discrepancy in the muscle vector angulation relative to the occlusal plane, was 7 degrees (for the temporalis muscle in the lateral view).

The measured geometric data from each of these test trials were entered into the computer and the model predictions were obtained for comparison. The conditions were again specified to be 100 units of biting force applied vertically, at four positions anteroposteriorly, along the right half of the tooth row. Any difference in the condylar load magnitude or the muscle force magnitude, was expressed as a percentage of the applied bite force. The average of the maximum differences in the resultant load on either the right or left condyles over the four anteroposterior bite positions for the three trials was 3.3 percent. The range of these maximum differences was 2.8 percent to 3.7 percent. The average values for the differences between the x-axis components and the y-axis components of the condylar loads for the three trials were 3.4 percent and 5.2 percent, respectively. The largest maximum difference between the three data sets for H-T Specimen #75, in the predicted force magnitudes for the muscles and condyles, was 6.2 percent of the applied bite force. This largest maximum difference occurred in the predicted muscle force values for the ipsilateral masseter. The average maximum difference in the direction of the load acting on the condyle was 5.6 degrees with a range of 5.1 degrees to 6.1 degrees.

The operator-related errors demonstrated through three test-trial tracings of H-T Specimen #75 showed relatively consistent measurements, and hence relatively small differences in the model predictions based on these measurements. The operator-related errors due to the selection of landmarks (and therefore the tracing and measuring of these landmarks as well) was shown to be small but greater in all respects, than the errors due to direct measurements without consideration of perspective effects.

2. Cephalometric Technique Errors

The limitations of, and errors associated with conventional cephalometric techniques and analyses have been described and discussed at length in the literature (Adams, 1940; Thurow, 1951; Hatton and Grainger, 1958; Bjork and Solow, 1962; Richardson, 1966; Baumrind and Frantz, 1971a and 1971b; Mitgard et al., 1974; Bergersen, 1980; Stabrun and Danielson, 1982; Ahlqvist et al., 1983; Tsao et al., 1983; Cohen, 1984). The problems are primarily related to the quality of the radiographs obtained and the interpretation of these radiographs.

In terms of the radiographs used in this study, those obtained from the osteological sample were of exceptionally high quality, and because the head position did not change for the lateral and the PA views, these radiographs provided a relatively accurate three-dimensional representation of the selected skulls and mandibles.

The clinical cephalometric radiographs had additional error considerations. For instance, they were made in a cephalostat which was rotated between views for patient repositioning, and which therefore were subject to repositioning errors. In addition, the superimposition of the soft tissues tended to complicate radiographic interpretation compared to the osteologic sample. Undoubtedly, there were potentially large errors involved in using clinical cephalometric radiographs to measure three-dimensional anatomic relationships. When employed with the experience gained from a conscientious, prospective study of an osteologic sample, these radiographs nonetheless offered information useful for the purposes of this study. The future prospect of cephalometric radiographs being used to obtain clinical information pertinent to mechanical function of the masticatory system is supported by the work reported herein.

V COMPARISON OF PHOTOGRAPHIC AND CEPHALOMETRIC TECHNIQUES

The geometric anatomic data describing a given osteological specimen, as obtained by the photographic technique, was compared to the geometric anatomic data describing the same specimen as obtained by the cephalometric technique. The individual measurements of anatomic relationships were expected to be quite different for the two techniques, due largely to the magnified image obtained from cephalometric radiographs. However, whether or not the same relative measurements collectively characterizing a particular masticatory system could be derived through the two techniques needed to be established. In order to do this, the numerical model was used to compare the cephalometric data set with the photographic data set for vertical bite forces of 100 units in magnitude, which were applied at four anteroposterior positions along the right half of the tooth row. The cephalometric data and the photographic data for each of the ten H-T specimens were run in the model and the results from the two techniques were compared for each specimen.

The average of the absolute difference between the predicted minimum resultant condylar loads for the ten H-T specimens, over the four bite force positions, was 8.6 percent with a range of 1.6 percent to 21.5 percent. The average of the absolute differences in the x-axis components and the y-axis components of the resultant condylar loads was 10.7 percent, with a range of 3.4 percent to 19.3 percent. The average of the maximum differences in the predicted masseter activity over the four bite force positions was 12.9 percent, with a range of 4.7 percent to 31.9 percent; while for the temporalis muscle, it was 12.0 percent, with a range of 3.3 percent to 21.6 percent. The largest values in the aforementioned ranges occurred in three specimens. The remaining seven specimens showed maximum differences between the predicted condylar loads and muscle forces of a smaller magnitude. The average maximum difference in the direction of the x-axis and the y-axis components of the resultant condylar loads was 7.0 degrees, with a range of 2.9 degrees to 14.4 degrees.

Tests were carried out in an attempt to account for the differences in the model predictions for the cephalometric technique data versus the photographic technique data for the same specimen. It seemed from preliminary analyses that the mechanical predictions for the model may be particularly sensitive to differences in condylar height relative to the occlusal plane, arch length relative to the position of the condyle, and the lateral-view angulation of the masseter muscle to the occlusal plane. For example, changes were made to the photographic technique data for H-T Specimen #66. Specifically, these changes entailed increasing the condylar height by ten millimeters, increasing arch length by five millimeters, and making the lateral-view masseter muscle vector-to-occlusal plane angulation more oblique by fifteen degrees. These changes simulated the measured values from the cephalometric technique for these parameters. The resultant predictions from the photographic technique data, when altered in this way, were very similar to those obtained from the cephalometric technique data.

A more detailed investigation into the observed differences in the model's predictions for the anatomic data from the two techniques will be required in the future. For the purposes of the present study, the consistency demonstrated between the results for the two techniques for the majority of the specimens in the osteological sample was felt to be satisfactory, particularly in light of the acknowledged error considerations associated with the individual techniques.

CHAPTER 4 RESULTS

I ANALYSIS OF FACIAL TYPE BY CEPHALOMETRICS

The anterior facial height and the relative inclination of the mandibular plane were the bases for the distinction made between the two facial type groups in the clinical sample. The eight long/steep cases and the eight short/flat cases were selected by clinical judgement, a qualitative assessment which was verified quantitatively by cephalometric measurements. The clinical sample represented two extremes in terms of facial type. For anterior facial height proportions and MPA measurements, the long/steep and short/flat groups generally fell outside the normal-range maxima and minima given for these features by the Manitoba Cephalometric Analysis standards (Table 4-1).

In terms of LAFH/TAFH, SNMPA, and FHMPA values, the two clinical sample groups were distinctly different. Student's t-test statistical analyses confirmed this at a 95% level of confidence. The long/steep group not only showed larger LAFH/TAFH values, but they also showed larger independent measures of TAFH. Mean TAFH for the long/steep group was equal to 137.4 millimeters $\pm$ 11.3 millimeters, while for the short/flat group it was equal to 117.0 millimeters $\pm$ 5.8 millimeters.

Plots of LAFH/TAFH versus SNMPA and FHMPA showed, in both cases, the existence of a relatively strong linear relationship between facial height proportions and MPA (Figure 4.1 and Figure 4.2). The linear regression

Table 4-1 COMPARISON OF THE LAFH/TAFH, SNMPA, AND FHMPA VALUES FOR THE CLINICAL SAMPLE GROUPS WITH MANITOBAN CEPHALOMETRIC ANALYSIS STANDARDS*

Measured Value	Manitoba Cephalometric Analysis Standards	Long/Steep Group	Short/Flat Group
LAFH/TAFH (%)			
Mean	56.57	59.6	54.1
Standard Deviation	-	± 2.6	± 1.6
Range	56.26 - 56.88	56.2** - 63.6	51.8 - 56.6**
SNMPA (degrees)			
Mean	32.0	45.6	22.4
Standard Deviation	-	± 7.1	± 3.4
Range	26.5 - 37.5	38.0 - 56.0	17.0 - 26.0
FHMPA (degrees)			
Mean	25.3	39.6	15.2
Standard Deviation	-	± 7.6	± 3.2
Range	20.6 - 30.0	31.5 - 53.5	11.5 - 19.5

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* Where: LAFH/TAFH = the ratio of Lower Anterior Facial Height to Total Anterior Facial Height

SNMPA = Sella-Nasion-Mandibular Plane Angle

FHMPA = Frankfort horizontal-Mandibular Plane Angle

** The lowest LAFH/TAFH value for the Long/Steep group and the highest LAFH/TAFH value for the Short/Flat group were found to be within the range of normal given by Manitoban standards for facial height proportions. For these two patients, only their MPA values verified their clinical categorizations when compared to Manitoban norms.

Figure 4.1 RELATIONSHIP OF LAFH/TAFH (%) TO SNMPA (DEGREES) FOR THE CLINICAL SAMPLE

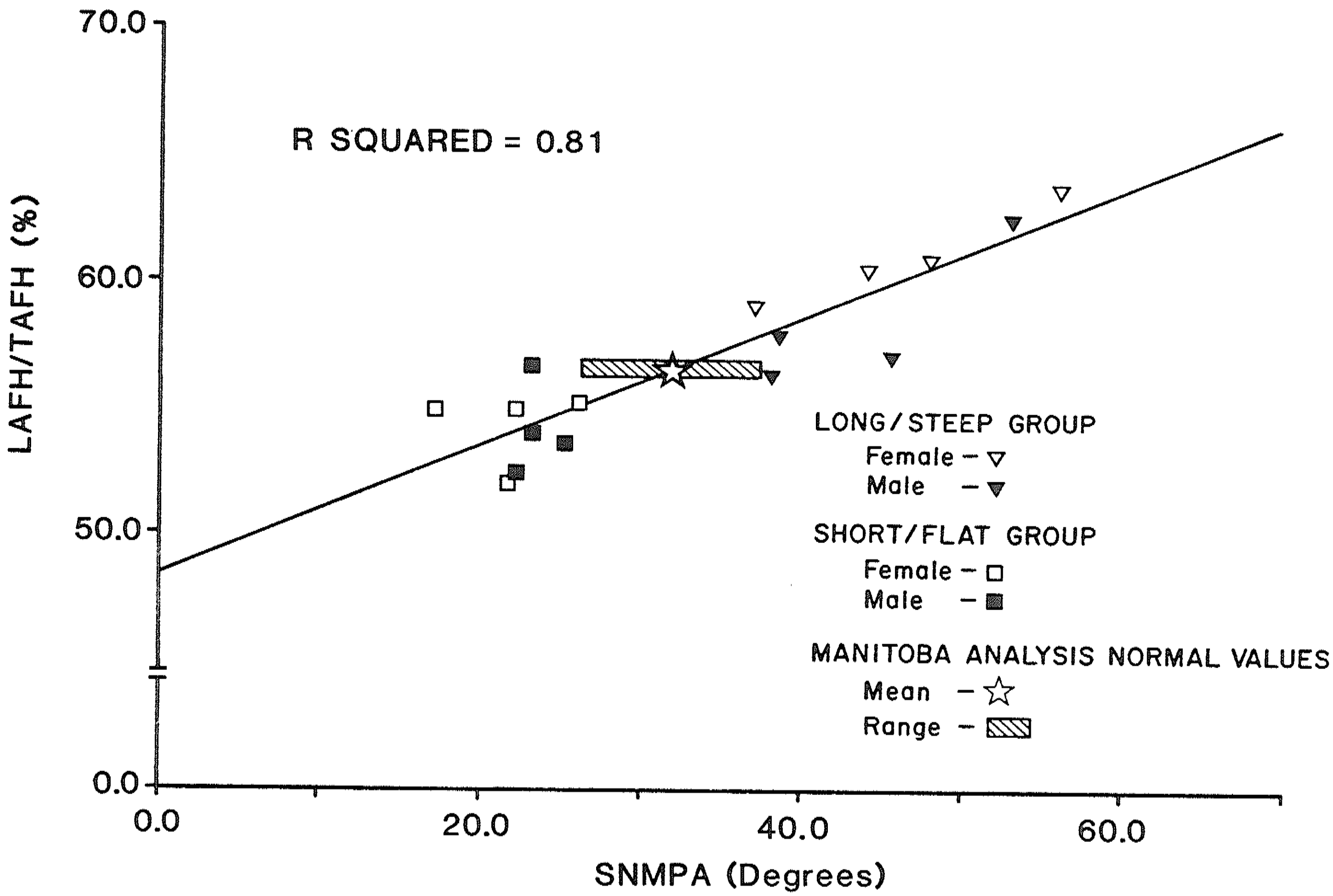
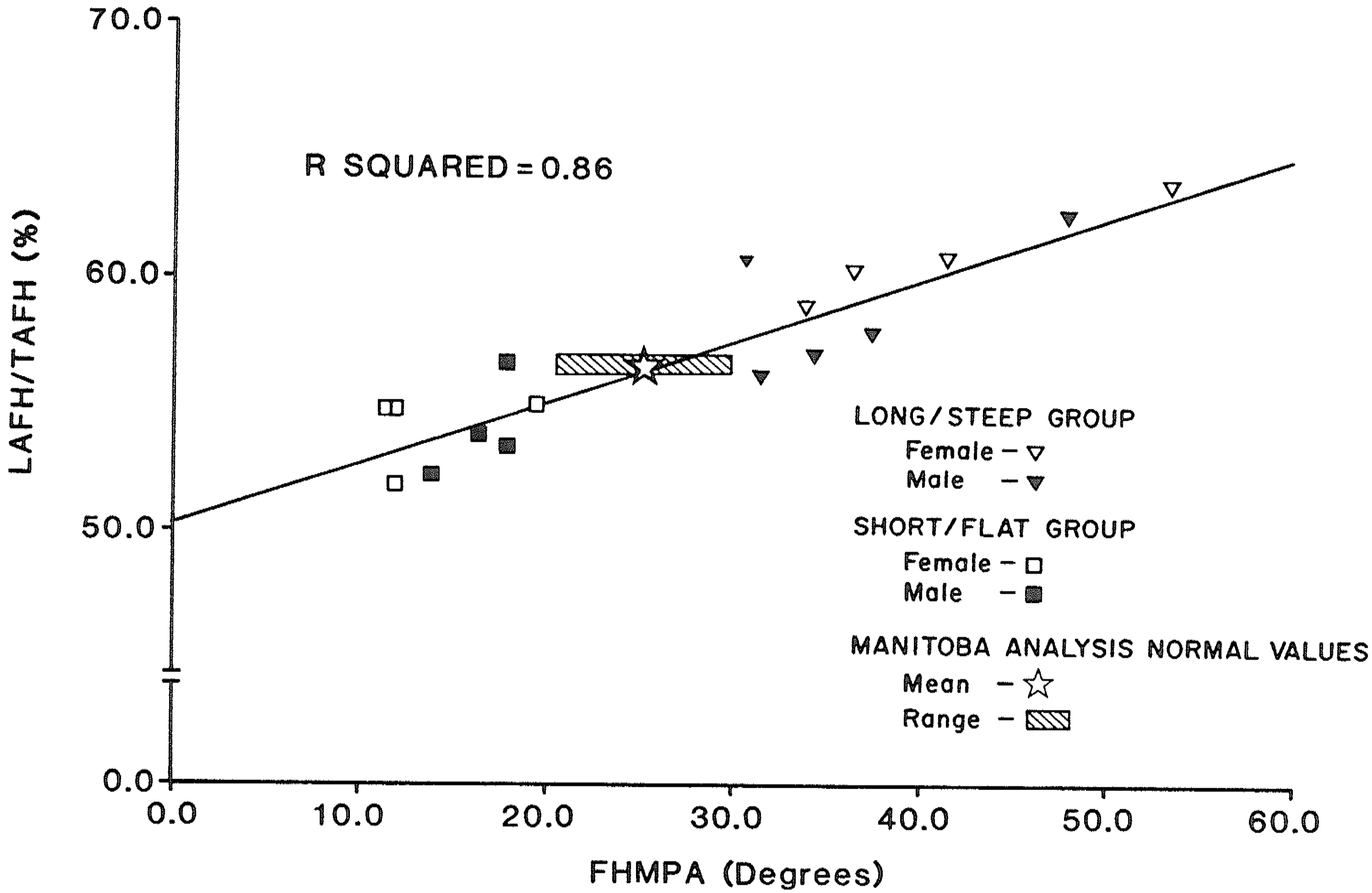


Figure 4.2 RELATIONSHIP OF LAFH/TAFH (%) TO FHMPA (DEGREES) FOR THE CLINICAL SAMPLE



coefficient for LAFH/TAFH versus SNMPA was 0.81, while for LAFH/TAFH versus FHMPA, it was 0.86. The Manitoba Cephalometric Analysis "normal" mean values and ranges for LAFH/TAFH, SNMPA, and FHMPA are indicated in Figures 4.1 and 4.2. These values were not included in the linear regression analyses by which the R-squared values and straight-line relationships characterized in the figures were derived. It should be noted however, that the corresponding Manitoba Cephalometric Analysis mean values and ranges fit very well with both the LAFH/TAFH versus SNMPA (Figure 4.1) and LAFH/TAFH versus FHMPA (Figure 4.2) plots of the clinical sample data. The Manitoba Cephalometric Analysis "normal" measurements appeared to be appropriate standards for comparing the selected individuals in the University of Manitoba clinical sample. This supports the initial assumption made in this regard (Chapter 3, III-1.).

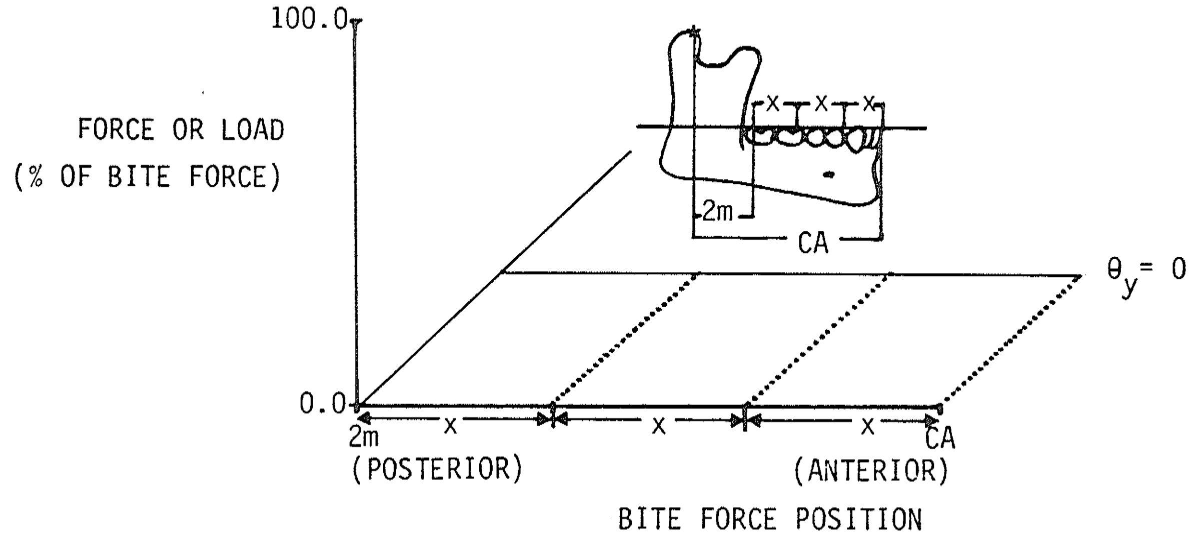
Trends with respect to age or gender of the subject were not expected for the given data (Table 3-1). The lack of sexual dimorphism for the parameters tested is shown in the Figures 4.1 and 4.2.

II ANALYSIS OF FACIAL TYPE BY THE NUMERICAL MODEL

The numerical model predictions for the muscle activity patterns and minimal condylar load for each of the individuals in the clinical sample were assessed for vertical isometric biting forces. These biting forces were assigned a magnitude of one hundred units, and were applied at four anteroposterior positions along the right side of the given mandibular tooth row. The results obtained from the model can be represented in the form of comprehensive three-dimensional plots. Figure 4.3 provides a labelled key to the information available from such plots, while Figures 4.4 and 4.5 show the plotted results for the described vertical biting conditions at four anteroposterior biting positions. Each horizontal row seen in the figures represents the model's predictions for an individual patient. Along each row, the muscle activities for the left and right masseter (ML, MR), lateral pterygoid (LPTL, LPTR), and temporalis (TL,TR) muscles at the four biting positions, and the resultant minimal left and right condylar loads (CL, CR) at the four positions, are displayed as a set. The results for the eight long/steep facial type patients are shown in Figure 4.4, while the results for the eight short/flat facial type patients are shown in Figure 4.5. All forces and loads are expressed as a percentage of the applied vertical biting force, the magnitude of which is shown by the length of the vertical axis on the left of each plot.

More specific, numerical data is presented in the following table (Table 4-2). This is the data corresponding to the most anterior bite force position only. It represents just a portion of the data provided by the model, but exemplifies the type of information available. References to the results shown in Table 4-2 will be made in the ensuing paragraphs.

Figure 4.3 MODEL PREDICTIONS: MUSCLE FORCE OR CONDYLAR LOAD FOR POSITION OF APPLIED BITE FORCE



"XL" or "XR"

where X = M - Masseter muscle force
LPT - Lateral pterygoid muscle force
T - Temporalis muscle force
C - Condylar load

L = Left side
R = Right side

* - Height of condyle
2m - Mandibular second molar position
CA - Central anterior position

θ_y - Angle of bite force from vertical

Figure 4.4 NUMERICAL MODEL PREDICTIONS FOR THE LONG/STEEP GROUP - VERTICAL BITING FORCE (See Figure 4.3 for key)

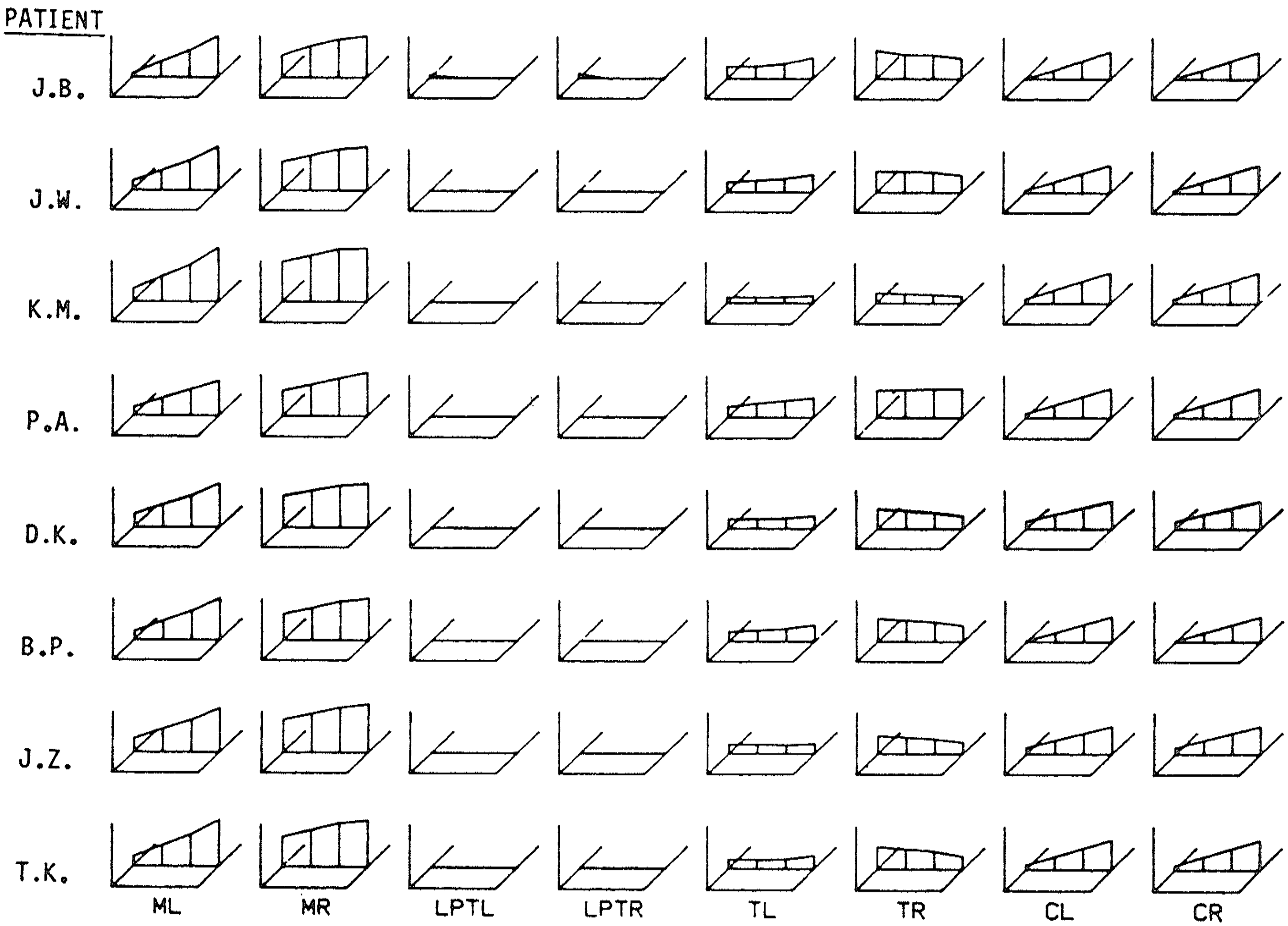


Figure 4.5 NUMERICAL MODEL PREDICTIONS FOR THE SHORT/FLAT GROUP - VERTICAL BITING FORCE (See Figure 4.3 for key)

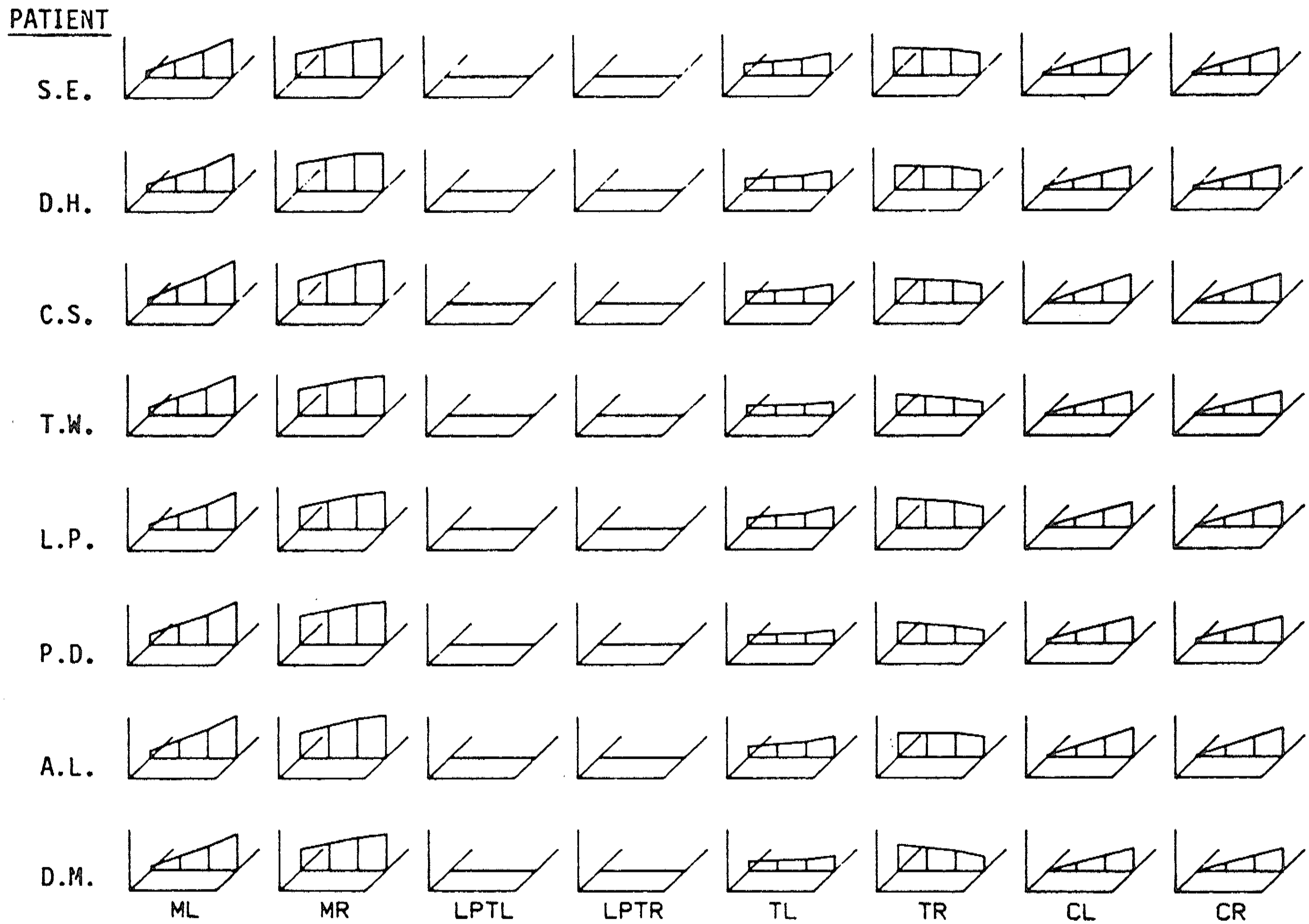


Table 4-2 THE UNIVERSITY OF MANITOBA CLINICAL SAMPLE: CONDYLE AND MUSCLE FORCE MAGNITUDES FOR VERTICAL ISOMETRIC BITING AT THE CENTRAL ANTERIOR POSITION*

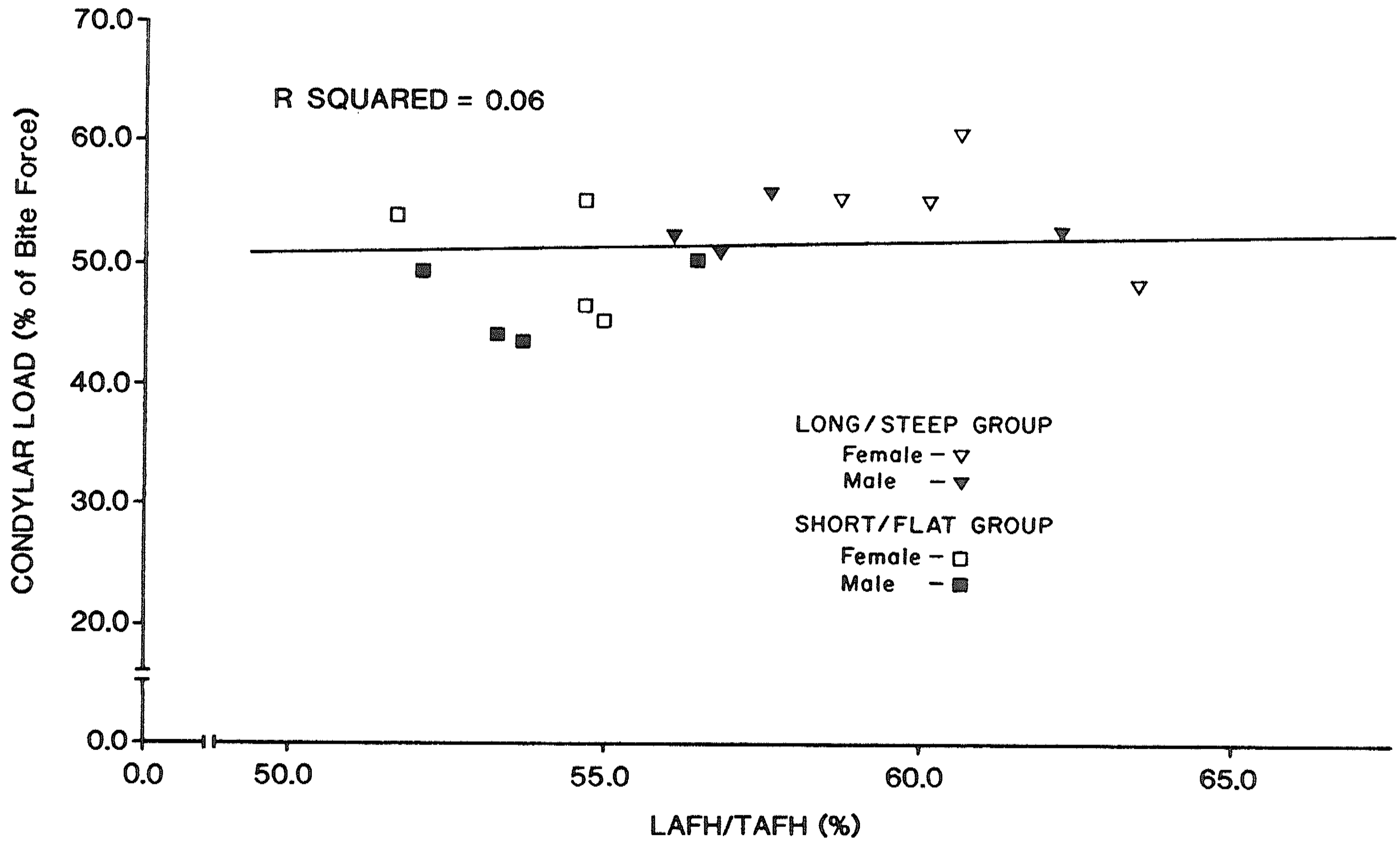
Patient (Sex)	Condylar Load	Masseter Muscle	Lateral Pterygoid Force(%)	Temporalis Muscle Force(%)	Masseter/Temporalis Force(%) Muscle Force Ratio
Long/Steep Group:					
J.B.(M)	51.3	79.0	0.00	39.4	2.00
J.W.(M)	52.6	84.3	0.00	33.2	2.54
K.M.(F)	60.8	105.1	0.00	14.2	8.40
P.A.(F)	55.6	75.2	0.00	46.1	1.63
D.K.(M)	56.2	89.2	0.00	25.6	3.48
B.P.(F)	48.5	80.8	0.00	31.4	3.57
J.Z.(M)	52.9	89.6	0.00	20.5	4.37
T.K.(F)	55.3	87.8	0.00	24.5	3.58
Mean values:	54.2	86.4	0.00	29.3	3.69
Ranges:	(48.5-60.8)	(75.2-105.1)	-	(14.2-46.1)	(1.63-8.40)
Short/Flat Group:					
S.E.(M)	49.8	74.2	0.00	41.8	1.78
D.H.(M)	44.6	73.2	0.00	36.8	1.99
C.S.(F)	54.4	84.6	0.00	36.2	3.34
T.W.(F)	45.7	78.0	0.00	25.6	3.05
L.P.(F)	47.0	69.8	0.00	39.1	1.78
P.D.(M)	50.6	83.2	0.00	26.4	3.15
A.L.(F)	55.5	83.0	0.00	40.3	2.06
D.M.(M)	44.0	71.0	0.00	28.2	2.52
Mean values:	49.0	77.1	0.00	34.3	2.46
Ranges:	(44.0-55.5)	(69.8-84.6)	-	(26.4-41.8)	(1.78-3.34)
Overall means:	51.6	81.8	0.00	31.8	3.08
Overall ranges:	(44.6-60.8)	(69.8-105.1)	-	(14.2-46.1)	(1.63-8.40)

* Forces are expressed as a percentage of the applied bite force and represent right/left averaged values.

A quantitative, comparative analysis of the predicted condylar load for vertical isometric biting at the central anterior position, demonstrated relatively little difference between the two groups. The central anterior position was chosen in order to simplify the comparative analysis. The magnitude of the loading of the condyles was maximal at this position for any given case (Smith et. al, 1986), and, since the applied bite force was central for this situation, the required muscle activity and resultant loads on the condyles were expected to be symmetrical (the same for right and left sides). The mean condylar load for the long/steep group (54.2%) was somewhat higher than the mean condylar load for the short/flat group (49.0%) at this position, but this difference was not statistically significant for the clinical population investigated to a 95% level of confidence. The numerical mechanical analysis of the masticatory systems of the clinical sample will be explored in more detail for this biting position.

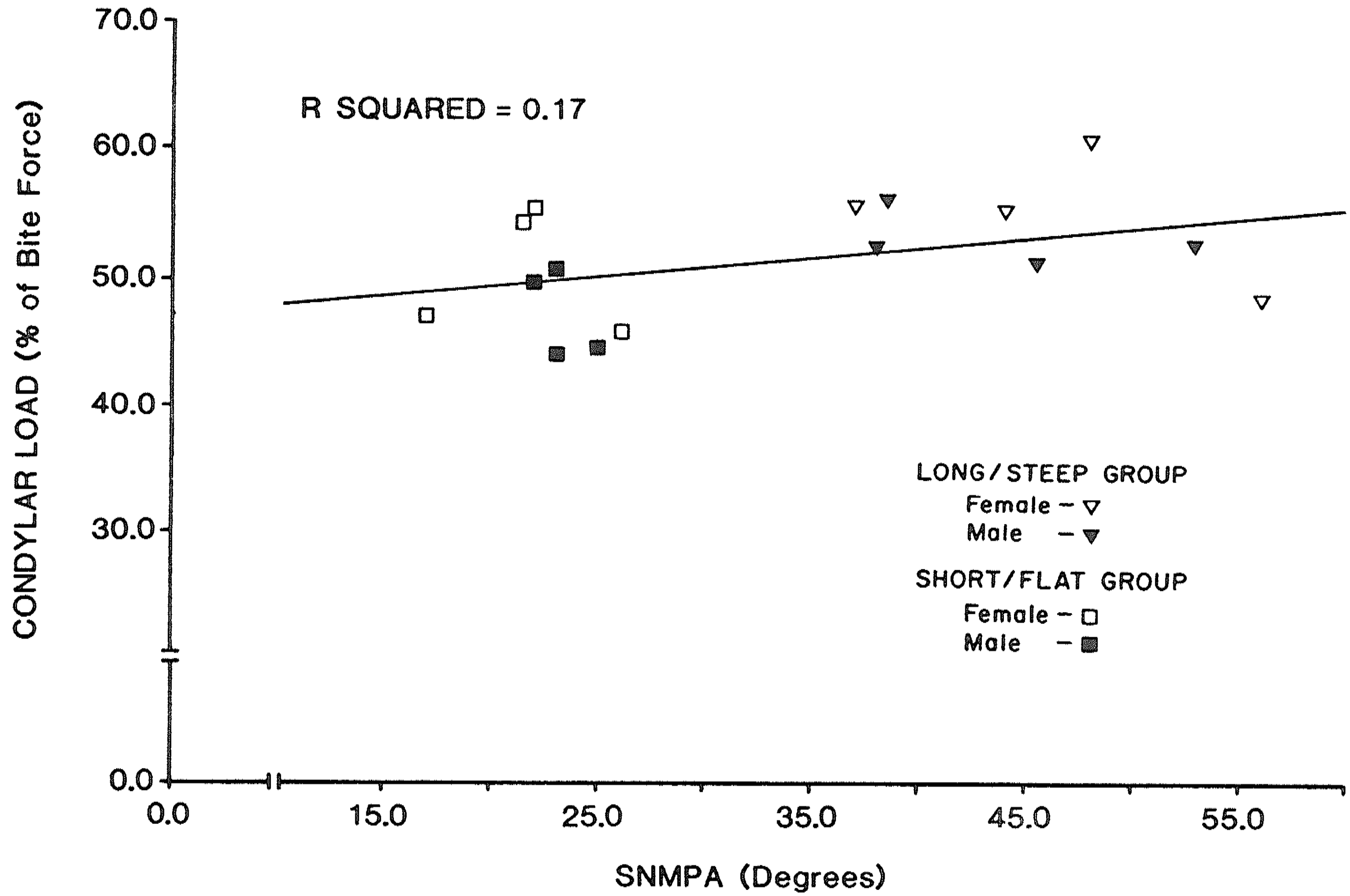
Condylar load at the central anterior position, expressed as a percentage of the applied bite force, showed no strong correlation to facial height proportions, or MPA for the individuals involved (Figures 4.6, 4.7, and 4.8). The linear regression coefficients for the plots of the condylar load versus the LAFH/TAFH, the condylar load versus SNMPA, and the condylar load versus FHMPA, for this sample, were nearly zero (0.06, 0.17, and 0.15, respectively), indicating poor linear dependence of the predicted condylar loads and the parameters characterizing

Figure 4.6 RELATIONSHIP OF CONDYLAR LOAD (% OF BITE FORCE) TO LAFH/TAFH (%) FOR THE CLINICAL SAMPLE*



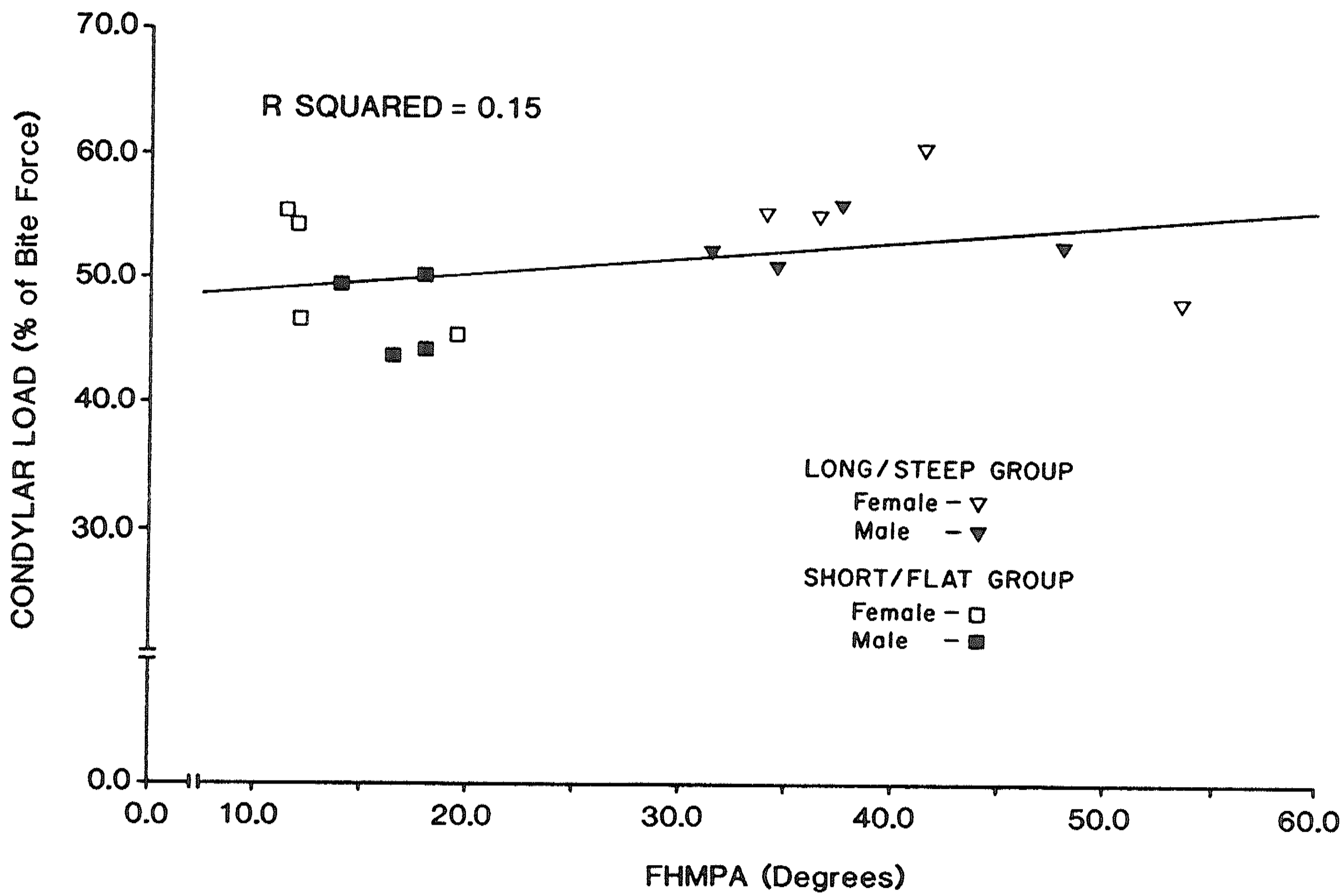
* For vertical biting at the central anterior position.

Figure 4.7 RELATIONSHIP OF CONDYLAR LOAD (% OF BITE FORCE) TO SNMPA (DEGREES) FOR THE CLINICAL SAMPLE*



* For vertical biting at the central anterior position.

Figure 4.8 RELATIONSHIP OF CONDYLAR LOAD (% OF BITE FORCE) TO FHMPA (DEGREES) FOR THE CLINICAL SAMPLE*



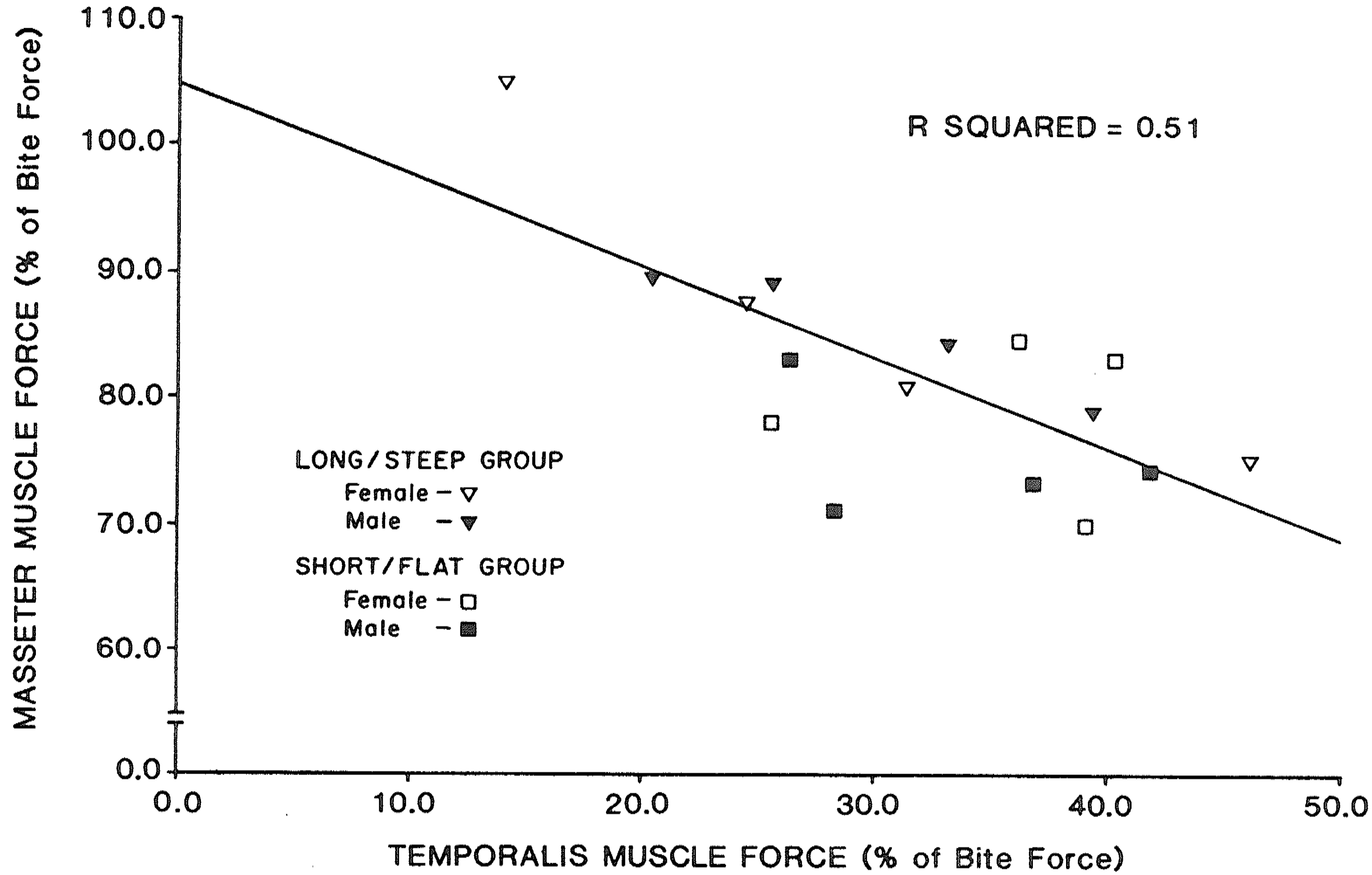
*For vertical biting at the central anterior position.

facial type.

The muscle activity patterns required to satisfy static equilibrium and minimize the load on the condyles were also analyzed for vertical isometric biting. In the survey shown in Figures 4.4 and 4.5, overall lateral pterygoid muscle inactivity was predicted by the model. The predicted masseter and temporalis muscle forces, on the other hand, showed some degree of activity at all four of the bite force positions surveyed. The observed masseter-temporalis muscle force patterns, with respect to bite force position, were investigated more closely. The model predictions for the situation of vertical biting at the central anterior position (Table 4-2) were analyzed. The masseter muscle force versus the temporalis muscle force for the clinical sample showed an inverse relationship of a linear nature for this situation (Figure 4.9). This was a relatively weak, but notable inverse relationship, with R-squared equal to 0.51.

The relative activity of the masseter and temporalis muscles was further explored. The ratio of masseter muscle force to temporalis muscle force (M/T) was used to represent the relative activity of these two muscles. Whether or not the M/T showed a relationship to facial type was therefore investigated by plotting M/T at the central anterior position versus both facial height proportions and MPA for all the individuals in the clinical sample. These plots failed to show any strong relationship between the muscle activity patterns and parameters used to distinguish facial

Figure 4.9 RELATIONSHIP OF MASSETER MUSCLE FORCE (% OF BITE FORCE) TO TEMPORALIS MUSCLE FORCE (% OF BITE FORCE) FOR THE CLINICAL SAMPLE*



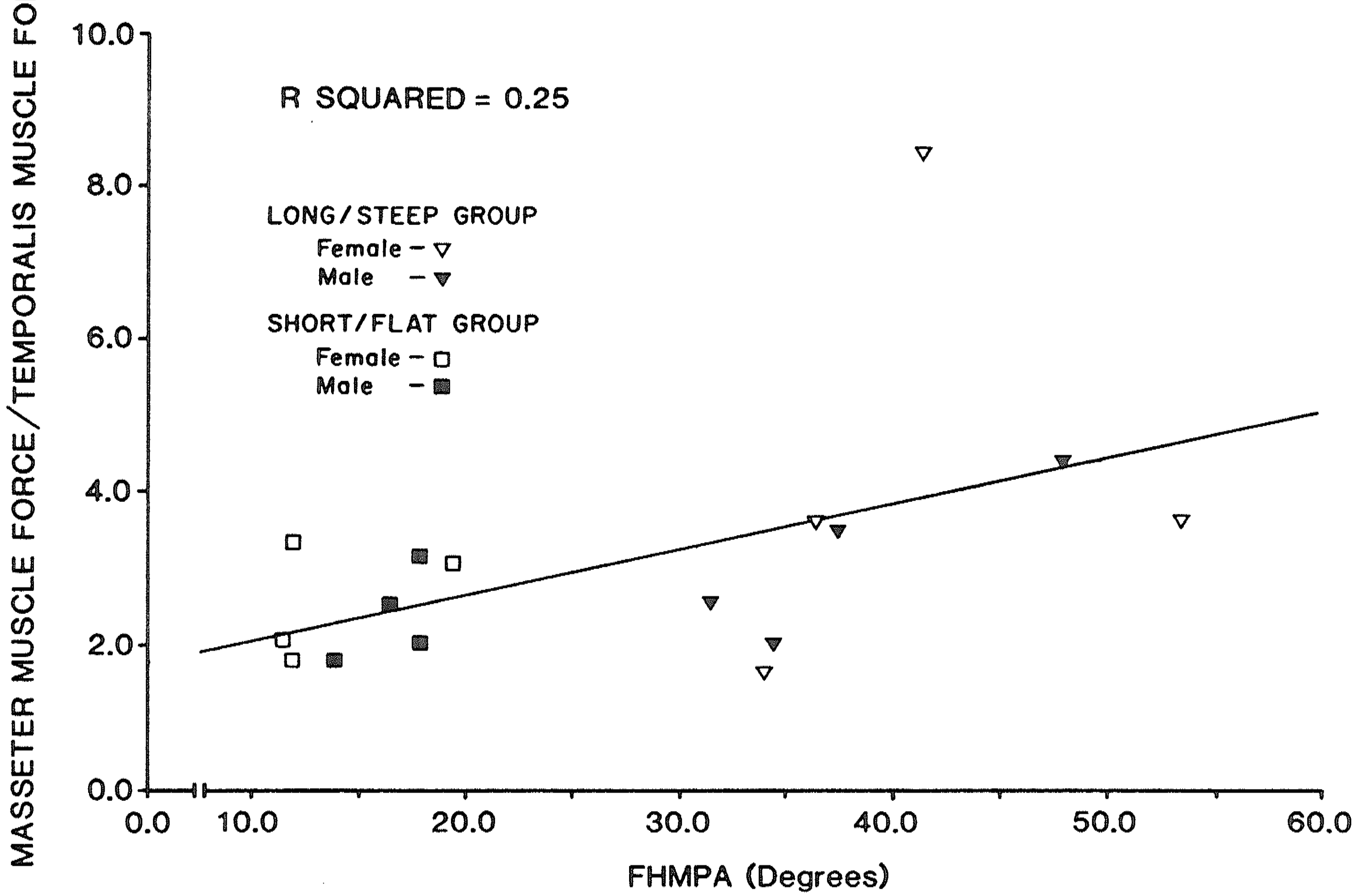
* For vertical biting at the central anterior position.

type (Figure 4.10 shows a representative plot). The correlation coefficients for M/T versus LAFH/TAFH, M/T versus SNMPA, and M/T versus FHMPA were 0.28, 0.26, and 0.25, respectively.

Compared to the rest of the sample, one individual in the long/steep group, patient K.M., generally showed very high condylar loads and masseter muscle forces, with low temporalis muscle forces predicted for all biting positions surveyed. These were particularly extreme at the central anterior position. The effects of this "extreme" data on the linear regression equations calculated for the sample were tested. The data associated with patient K.M. was excluded, and the linear regression equations were recalculated.

For the plot of the relationship between masseter muscle force and temporalis muscle force for the sample, when the data point representing patient K.M. was excluded, the linear regression coefficient decreased somewhat, from R-squared equal to 0.51 to R-squared equal to 0.32. Also, for the plots of condylar load versus MPA, analyses showed that the linear relationships were made worse when patient K.M. was excluded from the sample. For the plot of condylar load versus SNMPA, for example, the R-squared value changed from 0.17 to 0.10 when this patient was excluded. The extreme model prediction values for the patient K.M. therefore, did not appear to be masking stronger linear relationships between mechanical analysis predictions and conventional facial type parameters. In addition, they were not misleading in terms of possible masseter-temporalis

Figure 4.10 RELATIONSHIP OF MASSETER MUSCLE FORCE/TEMPORALIS MUSCLE FORCE TO FHMPA (DEGREES) FOR THE CLINICAL SAMPLE*



* For vertical biting at the central anterior position.

muscle associations for the sample group.

A separate analysis of the masseter muscle force versus temporalis muscle force relationship of the eight individuals representing the long/steep group only, showed a much stronger linear relationship (R-squared equal to 0.85) than the analysis of this relationship for the overall sample. Exclusion of the data point associated with patient K.M. in this situation, improved the inverse relationship between masseter and temporalis muscle forces for the long/steep group (R squared equal to 0.91). A much stronger masseter-temporalis muscle force relationship within the long/steep group was thus evident. Plots of M/T versus the cephalometric parameters of facial height proportions or MPA did not show strong links within this group. R-squared values were very low, including and excluding patient K.M.

The model predictions for the clinical sample investigated did not support strong facial type-specific characteristics in terms of condylar load and muscle force patterns for vertical isometric biting. In addition, no obvious sexual dimorphism was demonstrated in any of the parameters investigated (Figures 4.6, 4.7, 4.8, 4.9, and 4.10). As was found for the measures used to characterize facial type, the predicted condylar load and muscle force magnitudes did not show trends related to gender.

III ANALYSIS OF FACIAL TYPE BY ANATOMIC RELATIONSHIPS RELATIVE TO OCCLUSAL PLANE

As mentioned in Chapter 3, section V, tests using the model have shown notable sensitivities to certain anatomical parameters. In particular, the mechanics of the masticatory anatomy are affected by: arch length relative to the position of the condyles, condylar height measured perpendicular to the occlusal plane, and the lateral-view angulation of the masseter muscle to the occlusal plane. The model predictions did not vary widely between the long/steep and short/flat groups. It might therefore be expected that the aforementioned parameters also did not vary much between the facial type groups, despite their wide differences with respect to commonly used cephalometric measurements.

The relative anatomical geometric measurements and proportions of the two sample groups were therefore investigated relative to occlusal plane. All of the individuals showed a remarkable degree of similarity in terms of their functional masticatory anatomy when measured in this way. The parameters of arch length, condylar height, and lateral-view masseter angulations will be the focus of this section, but similar consistencies in other anatomic relationships, relative to occlusal plane, were also observed.

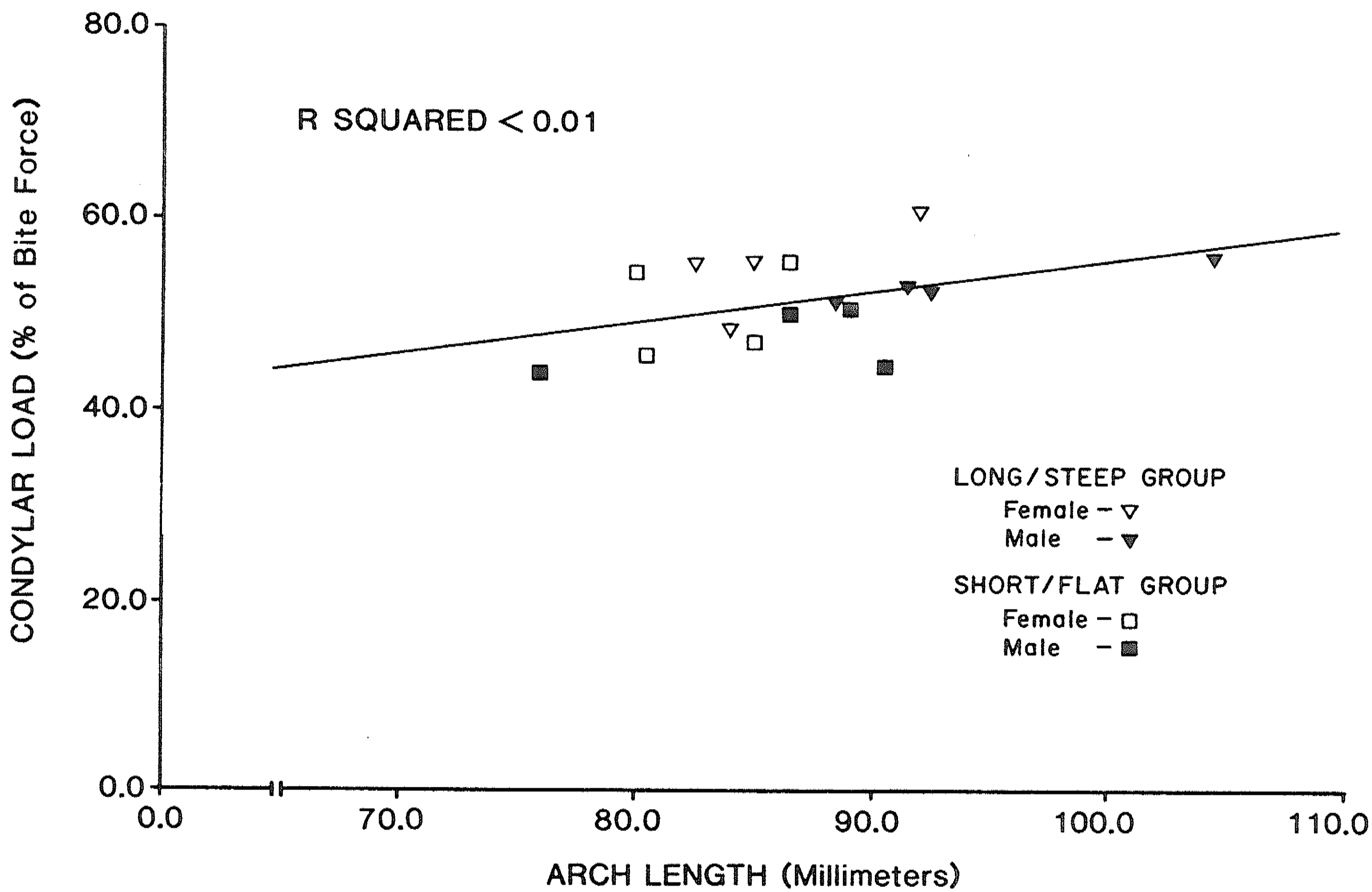
Larger predicted condylar loads for a defined bite force as it is applied at more and more anterior positions along a given tooth row have been reported (Smith et. al, 1986). Sensitivity tests in which arch length was extended also supported this. The effect of variations in arch length as demonstrated within the clinical sample was explored by plotting the relationship between condylar load at the central anterior position versus the arch length (Figure 4.11). For the sample group, the condylar load magnitude was not strongly related to the anteroposterior distance from the condyles at which the biting force was applied (R-squared, less than 0.01).

A closer look at arch length measured relative to the condylar position for the clinical sample showed that it did not provide a strong basis for distinguishing between the two facial types. The lack of anatomical distinction supported the lack of functional mechanical distinction predicted between the two groups. The mean value for arch length for the long/steep group was 90.1 millimeters, with a range of 82.4 to 104.5 millimeters. For the short/flat group, mean arch length was 84.3 millimeters with a range of 76.0 to 90.5 millimeters. Although the long/steep group showed a tendency towards slightly larger arch length values, a Student's t-test analysis showed no significant difference between these two groups in terms of arch length, to a 95% level of confidence.

Sensitivity tests in the model have also shown condylar height measured perpendicular to occlusal plane to be an important parameter with respect to mechanical function (Chapter 3, section V). However, the model predictions for the clinical sample groups did not imply strong correlations to condylar height, over the range of condylar height variations demonstrated by the sample.

Further analysis of the condylar height measurements of

Figure 4.11 RELATIONSHIP OF CONDYLAR LOAD (% OF BITE FORCE) TO ARCH LENGTH (MILLIMETERS) FOR THE CLINICAL SAMPLE*



* For vertical biting at the central anterior position.

the two facial types did not show this measurement to be closely associated with facial type. The mean condylar heights and ranges for the long/steep and the short/flat groups were 37.8 millimeters, with a range of 27.5 to 50.0 millimeters, and 38.7 millimeters, with a range of 33.5 to 43.5 millimeters. The facial type groups were not significantly different in terms of condylar height to a 95% confidence level.

The lateral-view masseter muscle vector angulation relative to the occlusal plane was also measured for all the individuals in the clinical sample. This angle tended to be higher for the individuals in the long/steep group, than for the individuals in the short/flat group, but this difference was not found to be significant to a 95% confidence level. The average value of the masseter muscle vector to occlusal plane angle in the lateral view, was 57.0 degrees, with a range of 52.0 to 73.9 degrees for the long/steep group, and 52.7 degrees, with a range of 43.5 to 59.0 degrees for the short/flat group. Linear regression analysis showed that the condylar loads predicted by the model for the clinical sample did not appear to be closely related to the measurement of this angle for the sixteen individuals investigated (R-squared equal to 0.20). Potential for relatively large errors in this angular measurement is acknowledged. Error considerations have been discussed in Chapter 3.

An investigation of the anatomical relationships of sixteen pre-orthodontic patients has shown that, when assessed relative to occlusal plane, their masticatory systems exhibit remarkably similar patterns of muscle function and condyle loading as determined by the numerical model. In addition, their component anatomical structures exhibit striking similarities. This is in contrast to the distinct differences in the anatomical relationships of these individuals when interpreted relative to conventional cephalometric reference planes such as SN and FH. Cephalometric analysis would divide the clinical sample into two groups, representing two very different facial types. An anatomical analysis relative to occlusal plane, and a mechanical analysis using a numerical model based on occlusal plane, do not support this categorization. The implication that marked morphological and mechanical differences exist between the long/steep and short/flat facial types has not been borne out by analyses relative to a functionally relevant reference plane.

CHAPTER 5 DISCUSSION

It is often assumed that craniofacial form is related to masticatory function, and hence, individuals showing extremely different dentoskeletal morphology might be expected to exhibit differences in terms of their functional mechanics. Sixteen pre-orthodontic patients from the University of Manitoba Graduate Orthodontic Clinic, have been studied in order to investigate possible relationships between form and function with respect to the chewing apparatus. These patients clinically and cephalometrically typified two distinct classes of facial form. That is, they were generally consistent with the classical definitions of "long-face syndrome" and "short-face syndrome." Specifically, they were selected to represent extremes in terms of facial proportions and MPA. The two extreme groups were therefore designated as "long/steep" and "short/flat," in reference to their respective anterior facial height proportions and mandibular plane inclinations. This distinction between the two facial types was verified by cephalometric analysis using conventional measures and reference planes (Table 4-1).

The mechanical aspects of the masticatory systems of these individuals, presumed to represent two distinctly different dentoskeletal forms, were analyzed using a three-dimensional numerical model. In terms of their predicted mechanical function however, the results did not show a marked distinction that would support the facial type classifications used (Figure 4.4 and 4.5). Further comparison revealed that, relative to occlusal plane, the geometric anatomic data representing an individual's basic masticatory system was not markedly different in terms of facial type. The differences in the functional masticatory anatomical relationships expected between the two conventionally recognized facial types were not found.

I Proportional Relationships

No single parameter is expected to account for the observed differences or similarities in the predicted mechanical function of the individuals investigated and described herein. Sensitivity tests in the numerical model have shown that significant changes to certain anatomical parameters can cause noteworthy changes in the predictions obtained from the model (see Chapter 3, section V). The individuals in the sample showing the largest and smallest measurements for a given parameter generally did not demonstrate large differences in their predicted functional mechanics, however. Consider the largest and smallest measurements of arch length for example, which were shown by patients D.K. and D.M.. The arch lengths, measured from the condyle to the CA position along the occlusal plane, were 104.5 millimeters and 76.0 millimeters, respectively, for these two patients, representing a relative difference of approximately twenty-seven percent. The predictions from the model for the two patients were not markedly different (Figure 5.1a) compared to the difference in the predictions

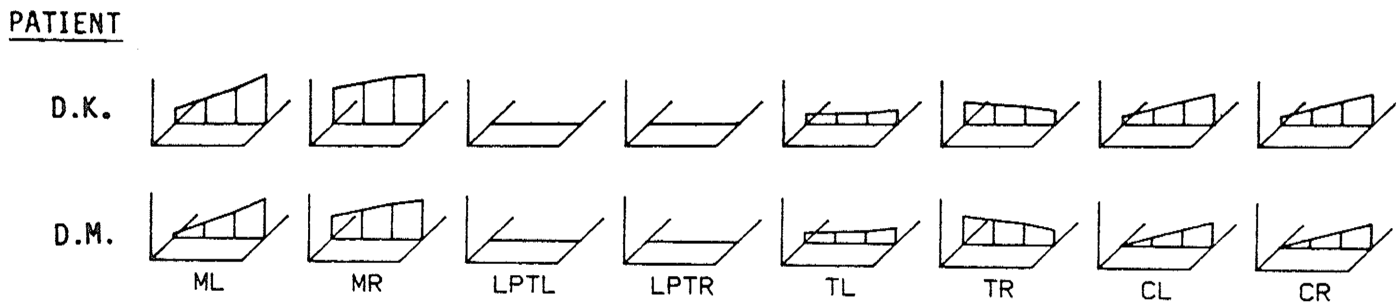


Figure 5.1a PREDICTIONS FROM THE MODEL FOR PATIENTS D.K. AND D.M.

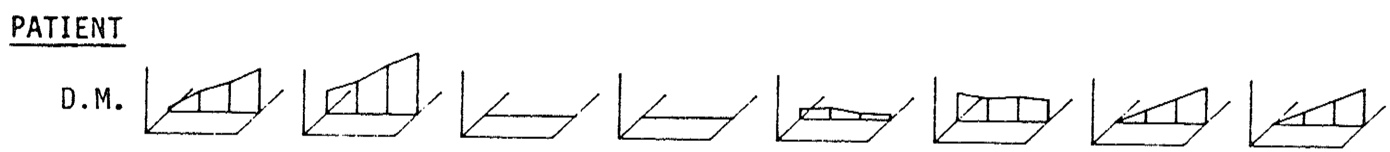


Figure 5.1b PREDICTIONS FROM THE MODEL FOR PATIENT D.M. - ARCH LENGTH INCREASED (27%)

from the model shown for patient D.M. in a test situation where the arch length for this individual was increased by twenty-seven percent (Figure 5.1b). Compensatory relationships in other parameters are thought to be responsible. The similarities in the predictions of the model for the sample group are believed to be a reflection of compensatory relationships between the functionally relevant, anatomical components of the masticatory system, existent in these people.

For the vertical isometric bite situation, investigated at four anteroposterior bite force positions, the model predicted a general shut down of the lateral pterygoid muscle (Figures 4.4 and 4.5). This was in agreement with the findings of Smith and co-workers (1986), and was thought to be associated with a relatively stable biting condition. The masseter and temporalis muscles, on the other hand, showed some degree of activity for the conditions surveyed, at all four bite force positions. The general form of the predicted masseter and temporalis muscle force patterns showed surprising consistency for the clinical sample group as a whole. The predicted force patterns for the masseter muscle or the temporalis muscle did not independently support a distinction between facial types. General trends between the masseter and the temporalis muscle force changes with anteroposterior changes to bite force position, were apparent however. These trends suggested an association between the masseter muscle and temporalis muscle forces required to minimize the resultant condylar loads at a given position. (R-squared for the relationship was found to be 0.51.)

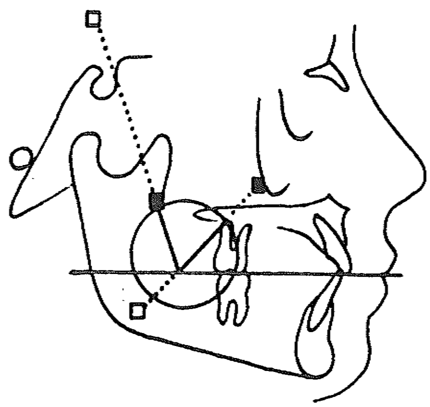
The relationship between the masseter and the temporalis muscle forces was further tested by investigating the M/T ratio versus facial type parameters. (See Chapter 4, section II.) A distinction between the clinically and cephalometrically determined facial type groups on the basis of M/T values for the sample, did not support a functional distinction between individuals regarded as morphologically distinct.

Through model sensitivity testing, it is known that changes to the arch length along occlusal plane, the condylar height, or the lateral-view masseter muscle vector-to-occlusal plane angle, affect the predicted condylar loads and muscle force patterns for a given biting condition. For example, changes to the central anterior and/or second molar position in the range of five millimeters or more, with all other parameters remaining unchanged, resulted in changes to the mechanical model predictions. Similarly, mechanical differences predicted by the model were associated with condylar height changes in the range of ten millimeters, and with lateral-view masseter muscle vector-to-occlusal plane angle changes in the range of fifteen degrees.

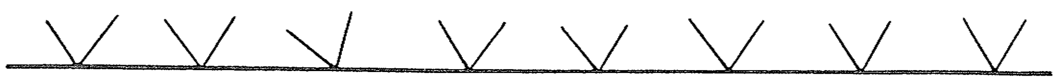
The model predictions for the clinical sample were surveyed. It was expected that any substantial mechanical differences might be accounted for by individual or group-specific differences in one or more of the aforementioned anatomical parameters. The numerical model predictions for the clinical sample were found to be very similar however. This was somewhat surprising, so a closer investigation of the range of anatomical parameter variations for the sample was carried out. This showed that the true variation in the relative geometry within the total sample was, in fact, very small. For example, the distance from the central anterior position to the second molar position along the occlusal plane in the sagittal view, was very consistent for the sample, having an overall mean equal to 43.4 millimeters, with a standard deviation of $\pm$ 2.9 millimeters. There was no statistically significant facial type-specific difference in arch length to a 95% level of confidence. Within an individual system, the relationships between tooth row, condylar position, and muscle vector angulations, appeared to be complementary in that similar proportions for the entire sample group were demonstrable (See Appendix B for a table containing this data).

The similarities in the geometric anatomical relationships of the sample were further shown by the fact that proportions of arch length to condylar height and intercondylar distance were remarkably consistent. The overall mean of the relationship between (condylar height)(intercondylar distance)/(arch length) was equal to 1.2 "millimeters," with a standard deviation of $\pm$ 0.2 "millimeters;" and no statistically significant facial type-specific difference, to a 95% confidence level. A similar degree of consistency was seen in the angular measurements studied, though, as discussed in Chapter 3, a relatively large potential error, which was in part, inherent in the operator, was recognized in these muscle vector-associated angles. Nonetheless, the range of values for the angle formed between the lines of direction of the masseter muscle vector and the temporalis muscle vector in the lateral view, was found to be quite small. The overall sample mean for the angle formed by these lines was equal to 65.8 degrees, with a standard deviation of $\pm$ 4.5 degrees. Students' t-test statistical analysis showed no significant difference between the two facial type groups for this angle to a confidence level of 95%. Masseter and temporalis muscle vector angulations relative to occlusal plane in the lateral view therefore showed a complementary relationship. Where masseter muscle vector angulation to occlusal plane tended to be more oblique, the temporalis muscle vector angulation to occlusal plane tended to be relatively upright, and *vice versa*. Figure 5.2 shows these angles relative to occlusal plane.

It seems that proportional relationships important to mechanical function, exist between the anatomic parts of the masticatory system. Differences in these proportional relationships may be responsible for the differences in the model predictions for individual masticatory systems. The initial investigations carried out for the clinical sample, using the numerical model support this. For example, an



LONG/STEEP GROUP: (Patient - Degrees)



Patient:	JB	JW	KM	PA	DK	BP	JZ	TK
Degrees:	69.0	68.0	68.0	66.0	63.0	77.0	62.0	61.0

SHORT/FLAT GROUP: (Patient - Degrees)

Patient:	SE	DH	CS	TW	LP	PD	AL	DM
Degrees:	68.0	69.0	67.0	62.0	71.0	62.0	68.5	55.0

Figure 5.2 MASSETER AND TEMPORALIS MUSCLE VECTOR ANGULATIONS TO OCCLUSAL PLANE (LATERAL VIEW)

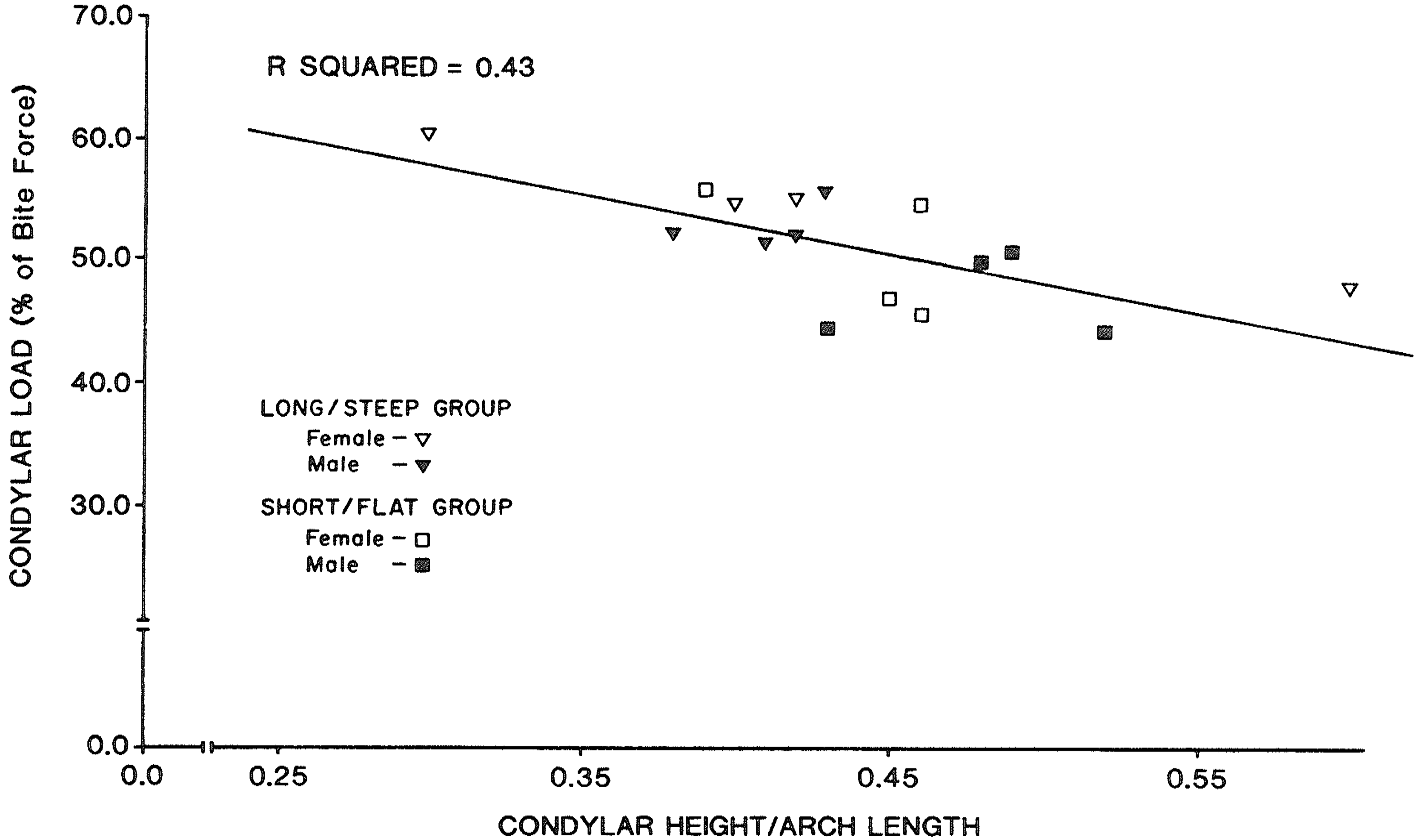
analysis of condylar load versus the ratio of condylar height to arch length (Figure 5.3), suggests that a relationship may exist (R-squared equal to 0.43). Further investigations to fully define the anatomic proportional changes responsible for significant effects on the mechanics of masticatory function, are left to future work.

II Relevance of Findings to Clinical Treatment

By normal orthodontic standards the clinical sample studied demonstrated a moderate to severe degree of dentoskeletal malformation. Despite this relative "abnormality," none of these malformations could be said to be life-threatening. All of the patients were, in fact, found to be in good general health. It has been implied that form and function are closely related. Severe, compromising effects of the "abnormal" form demonstrated by the clinical sample on the essential functions of mastication, speech, deglutition, and perhaps social behaviour, were not evident. It seems that the question regarding the relationship between "abnormal" form and "abnormal" function has not been adequately defined. This study has focused on a limited aspect of this relationship.

Evidence for the existence of consistent or complementary functional, anatomical relationships in persons outwardly exhibiting very different dentoskeletal form, sheds interesting light on the debate over the relationships between anatomical form and masticatory function. Conventional thinking with respect to differences

Figure 5.3 RELATIONSHIP OF CONDYLAR LOAD (% OF BITE FORCE) TO CONDYLAR HEIGHT/ARCH LENGTH FOR THE CLINICAL SAMPLE*



* For vertical biting at the central anterior position.

in dentofacial morphology has presumed concomitant differences in masticatory function. Clinically and cephalometrically judged extremes in facial type, were demonstrated by the eight long/steep group patients and eight short/flat group patients studied here. These two types of individuals are traditionally considered to be "abnormal" and to demonstrate undesirable dentofacial patterns. Many patients classified as exhibiting "long-face syndrome" or "short-face syndrome" undergo major orthodontic and/or orthognathic surgical treatment. This was subsequently the case for fourteen of the sixteen patients included in this study. Such treatment is advocated in order to address major dentoskeletal "discrepancies." It is intended to harmonize the dentoskeletal relations by making them approximate more "normal" or average relations. The objectives of this treatment are to not only correct esthetic problems by making the patient look more "normal" or average, but supposedly to correct functional problems as well.

The mechanical analysis of the masticatory function of the sixteen individuals selected, did not support their clinical and cephalometric categorization. General similarities were noted between all individuals studied, in terms of the functional anatomic components of the masticatory systems when compared relative to occlusal plane. This would suggest that the human system, in its development, compensates well, in the mix of anatomical structures necessary to maintain function adequate for survival. Examples of the effects of function on form are plentiful. Consider the effect of a prolonged digit-sucking habit on the dentoskeletal relationships, for example. Masticatory function is expected to similarly influence the growth and development of the component parts involved in mastication. As a result, compensatory relationships between the components important to mastication, reflect the influence of functional demands on the underlying genetic predisposition for form.

Some of the higher condylar loads predicted for the sample occurred for bite forces applied at the central anterior position in the five long/steep group patients who clinically demonstrated anterior open bite malocclusions (Patients J.W., D.K., B.P., J.Z., and T.K. in Table 4-2). It may be hypothesized that the development of an anterior open bite reflects a compensation to discourage incisor biting, in individuals where relatively high loads on the condyles would result. In the future, this could be further explored using the numerical model.

The existence of compensatory relationships may also help to explain orthodontic relapse subsequent to treatment to "improve" form. Such improvements, as they are regarded, generally mean changes in form to meet conventional orthodontic concepts of ideal occlusion and facial balance. These ideals are largely based on derived systems of reference. Changes in form to meet these concepts may not comply with the functional demands of the dentoskeletal unit. Awareness of this is a treatment imperative. Proportional relationships between the functional anatomic components of the masticatory system are evident through this work. Changes in form which violate these functional relationships may compromise and/or damage the underlying health of the chewing apparatus. The use of orthodontic and orthognathic surgical procedures to make gross changes to the dentoskeletal relations in order to "improve" dentoskeletal and facial harmony and balance, is put into a new perspective by the results presented in this thesis.

III Planes of Reference

The findings from this investigation call into question the use of conventionally derived planes of reference. It seems that popular reference planes such as SN and FH, may not be universally appropriate to the assessment of dentoskeletal and facial form. In terms of the functional mechanical analysis of the components of the dentoskeletal system involved in isometric biting at least, the use of such traditional planes of reference is in fact misleading.

The two groups of eight individuals, represented two distinctly different morphological types, the "long-face syndrome" or dolicofacial type, and the "short-face syndrome" or brachyfacial type. According to both clinical judgement and cephalometric measurements (LAFH/TAFH, SNMPA, and FHMPA), the two groups demonstrated extreme differences in dentoskeletal and facial form.

Through a functional analysis of the mechanics of the anatomic components involved in vertical isometric biting, the masticatory systems of the clinical sample were not found to be extremely different. This functional analysis did not support the division of the clinical sample into two distinct facial type groups. Despite the given dentofacial form as assessed clinically and as interpreted relative to SN or FH reference planes, it seems that the functional relationships within an individual system were such that adequate mechanical function could be possible. The reciprocal influences of form on function and function on form, may thus direct the growth and development of the masticatory apparatus in a manner that would optimize the mechanical relationships required for essential functions, within the genetic dictates governing form. The characteristic dentoskeletal patterns observed in certain facial types thus may demonstrate important compensatory relationships. These relationships may have developed through the influence of functional demands imposed on a basic, inherited morphological pattern. These relationships, which are important to the mechanical aspects of function should not be expected to have direct or special relevance to such planes of reference as SN or FH.

In the analysis of the functional relationships of a given masticatory system for any morphological "facial type," important information is to be gained through the use of a plane of reference which is relevant to the function of that system. The occlusal plane for example, should have more functional relevance to the chewing apparatus than FH or SN. If the reciprocal influences of form and function are to be recognized and respected in the treatment of dentofacial disharmony or "abnormalities," functional as well as morphological relationships must be appropriately assessed and addressed in all phases of treatment. This thesis contends that the SN and FH planes of reference are not appropriate to the assessment of the functional occlusal relationships which characterize a given system.

Dentofacial form that is judged to be "abnormal," may constitute a real and valid concern from a number of perspectives. Orthodontic standards regarding "normal" and "abnormal" dentofacial form are linked to societal standards and personal tastes. Facial form and esthetics are known to influence social behaviour and interactions (Macgregor, 1970; Lansdown, 1981; Kiyak et al., 1986). In almost all forms of communication media, the association of facial form with personality and behavioural characteristics finds prominent use. As well, there are strong functional implications associated with facial form and esthetics from the personal, societal, and dental standpoints.

Achieving more "normal" dentofacial relationships, is generally the primary goal for those individuals exhibiting "abnormal" dentofacial form, who seek treatment and/or for whom treatment is advocated. Because of the suspected close relationship between form and function, those patients with "abnormal" form are often assumed to function "abnormally" as well. It is felt that by attaining more "normal" form, improvements to function will tend to follow. In cases where major morphologic changes are to be made through orthodontics, with or without orthognathic surgery, it seems imperative that functional considerations as well as esthetic considerations be addressed. The study of the functional aspects of an individual masticatory system should be a separate and conscientious effort. Its purpose should be to achieve functional improvements through treatment, or at least to ensure that function is not compromised by treatment to improve the dentofacial esthetics. Both the pre-treatment and the potential post-treatment situation with respect to function, must be carefully assessed.

The numerical model provides one means of evaluating the mechanical aspects of function for conditions of isometric biting, using a functionally relevant reference plane. This is in contrast to the more traditional assessments of dentofacial form which are made relative to FH, SN, and other reference planes. This model provides an opportunity to evaluate form with respect to function using occlusal plane as the reference plane. Criticism regarding the difficulty in defining, and the error associated with locating occlusal plane (as discussed in Chapters 1 and 3) has been commonly voiced. Despite this however, the occlusal plane seems a far superior reference from which to assess the mechanics of the functional masticatory ability existing, and consequent to changes in form.

IV Range of Variation

For the sample overall, the ranges of variation were not outstanding for the various anatomical parameters measured relative to occlusal plane. It is worth noting however, that for all parameters, the ranges of variation observed for the long/steep group were greater than the ranges of variation observed for the short/flat group. This is in agreement with the literature, which purports that certain features of facial morphology vary less in persons of the short/flat facial type due to the relatively stronger musculature found in these people (Ingervall and Helkimo, 1978). It is therefore implied that brachyfacial types demonstrate a greater effect of function on form.

V Sexual Dimorphism

As mentioned in Chapter 4, sexual dimorphism was not demonstrated in any of the parameters quantified by cephalometric measurements or by geometric relationships relative to occlusal plane. Since the geometric relations were not gender-specific, it followed that the model predictions were not gender-specific either. It seems that, despite the differences in gross size of anatomical parts, and muscular strength generally associated with gender, the proportional relationships of the dentofacial systems studied did not show trends associated with gender.

CHAPTER 6 CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

I Conclusions

The functional importance of conventional facial typing has been investigated. The mechanics of the human masticatory systems characterizing two very different facial types were analyzed using a three-dimensional numerical model. The geometric anatomic relationships relevant to isometric biting in eight dolicofacial (LFS) patients and eight brachyfacial (SFS) patients were thus compared. As a result of this work, the following conclusions have been made:

1. The conventionally defined facial types investigated were found to be surprisingly similar in terms of predicted functional mechanics for the isometric bite situation. Furthermore, in terms of the geometric anatomic relationships representing their masticatory systems,the two facial types were found to be very similar.

2. The Frankfort horizontal and the Sella-Nasion reference planes, commonly used to distinguish facial types, do not have direct relevance to masticatory function.

3. The occlusal plane is a reference plane better suited to a functional analysis of the chewing apparatus.

4. Three-dimensional data representing the geometric anatomical relationships of the masticatory system, can be obtained for mechanical analysis from clinical subjects.

II Improvements to the Cephalometric Technique for Three-Dimensional Data Collection

The conventional applications of cephalometric radiography to orthodontics have been generally discussed in Chapter 1. Presently, most commonly used cephalometric analyses are based almost exclusively on lateral cephalometric radiographs. One of the important uses of the cephalometric technique as it was first advocated by Broadbent (1931) however, was to obtain three-dimensional measurements of dentoskeletal relationships from standardized radiographs taken from both lateral and posteroanterior views. Reliable, three-dimensional, anatomical measurements made of clinical subjects would be extremely desirable for mechanical analysis using the McLachlan-Smith numerical model. This has been attempted. Some of the errors and problems associated with the use of conventional cephalometric radiographs to obtain the desired three-dimensional geometric anatomic data for use in the model, have been discussed in Chapter 3, section IV-2. Additional suggestions for improvements to the radiographic method are now offered.

The numerical model shows that the mechanics of the masticatory system are sensitive to changes in certain parameters. In particular, the model predictions are affected by changes in arch length, condylar height, and the lateral-view masseter muscle vector-to-occlusal plane angle. With these sensitivities in mind, in the future, steps may be taken to minimize the measurement errors associated with these parameters.

The future investigator could benefit greatly by having the opportunity to examine the subject clinically, prior to x-ray exposure for the cephalometric radiographs. Radio-opaque markers could be temporarily attached to the teeth in a manner that did not interfere with the occlusion or lip posture. These markers would help to more accurately locate the positions of the teeth, and thus improve the reliability of the arch length measurements and location of the occlusal plane. Direct measurement of relative tooth positions in the mouth or from accurate study models could be an additional help to verify relative tooth positions measured radiographically.

Through the clinical examination, the investigator could also determine the approximate height of the condyles. Palpation in the area lateral to the condyle, while the subject moved the jaw through a limited range of opening and closing, and side-to-side movements, would help to locate the area of the face external to the condyle. This area could then be marked temporarily with a radio-opaque marker, and later used as a guide to the location of the condylar head on the radiograph.

The superficial masseter muscle and perhaps the temporalis muscle also, could be palpated during the clinical examination. The location of the muscle centroids and the direction of muscle pull for the isometric bite situation could thus be clinically assessed. Radio-opaque markers attached to the skin could serve adjunctively as guides to the location of muscle centroids and the direction of muscle pull.

The radio-opaque imaging parameters used to obtain the cephalometric radiographs could be improved in future. These parameters could be adjusted more specifically for the improved visibility of the anatomical part of interest. The condyles, for example, are not always clearly seen in clinical cephalometric radiographs. Such improvements to the radiographic image definition can be achieved with very small changes in the radiation exposure to the subject (Hatcher, 1987).

A final suggestion with respect to further improvements to the cephalometric technique, regards additional testing to better verify the accuracy of this technique. Osteological specimens should be radiographed with and without radio-opaque markers for tracing by the same operator. The accuracy of the measurements determined from the unmarked specimens compared to the marked specimens would give a further indication as to the degree of accuracy expected for this aspect of the technique. Appropriate steps should of course be taken to avoid operator bias in such tracings. This could be accomplished by having the operator trace a number of unidentified, marked and unmarked radiographs, not all of which would be matched pairs.

III Establishment of Critical Proportional Relationships

The results of preliminary studies with the numerical model have suggested that the mechanics of the masticatory system may be more sensitive to variations in certain anatomic relations and proportions than others. The relationships believed to be critical, such as that of arch length to condylar height and intercondylar width, and the lateral-view angulation of the masseter muscle to occlusal plane, should be more fully tested in the model. The exact nature and magnitude of these critical relations and proportions should be determined in the future.

The results reported in this thesis could serve as a guide to such future work. Clues as to the anatomical relationships most important to the model may be found by examining and comparing the results of the anatomical versus the model analyses for the individuals in the clinical sample. For instance, out of the entire clinical sample, the predicted condylar load was the highest for patient K.M. for the conditions surveyed, for all bite force positions except the most posterior. Linear regression analyses indicated that the predictions pertaining to patient K.M. belonged with those of the group assessed, but represented the extreme within this group. Investigation into how patient K.M. differed from the rest of the clinical sample in terms of anatomic parameters and proportions should firstly be performed. These differences could then be tested in the model to see which might account for the predictions of higher condylar loads.

As well, the effects of breadth parameters on the mechanics of the masticatory system for the conditions of non-vertical biting, should be explored with respect to facial types. The widths of the face, jaws, and dental arches are all features characterized by definitions of facial type. The focus of orthodontic treatment and diagnosis, however, especially as it pertains to the use of cephalometrics, has largely emphasized dentoskeletal characteristics evaluated in the lateral view. Breadth considerations in the anatomic components of the masticatory system were not emphasized in this study since the biting conditions investigated were restricted to vertical biting forces applied at a centred, anterior position in the dental arch.

IV Further Development of the Numerical Model as a Clinical Tool

Steps to further develop the numerical model as a clinical tool are already underway. Preliminary EMG experiments have been carried out with regards to validation of the model (McLachlan, 1987). As well, work towards modifications to accommodate motion studies are currently being undertaken.

It is expected that verification and development of the model through objective clinical testing, based on sound theoretical hypotheses, will substantially enhance the fundamental understanding of the mechanics of the masticatory system. Functional considerations with respect to the chewing apparatus could thus be more conscientiously addressed in the development of clinical treatment plans for orthodontic, orthognathic surgical, prosthodontic, and temporomandibular joint dysfunction cases.

The verified model will provide a means for an <u>a priori</u> evaluation of any treatment which results in alterations to the occlusal plane. It will, therefore, be significant in particular to the planning and evaluation of orthodontic, orthognathic surgical, and prosthodontic procedures. The ability to evaluate the effects of changes to the occlusal plane on the mechanics of the masticatory system, should allow a more prevention oriented approach to treatment, paying due regard to the possible long term effects of the treatment on temporomandibular joint integrity, occlusion, and esthetics.

The numerical model could, in future, also serve as a useful research tool for clinical investigation into temporomandibular joint function. Approporiate treatment may be more accurately applied, as a result, to diagnosed cases of temporomandibular joint dysfunction. For example, the mechanical effects of occlusal splint therapy could be ascertained. That is, knowledge gained from the model as to the pattern of muscle accommodation to occlusal splints, would enhance the understanding of the effects of mandibular repositioning splints in comparison to relaxation splints.

It is hoped that objectives for occlusal function, optimally suited to the facial form of each patient, will be ultimately identified through future research. The goal, more specifically, is to achieve an improved understanding of the relationships between skeletal morphology, the muscles of mastication, and patterns of functional tooth contact. In this way, the numerical model could not only provide an improved theoretical basis for the planning, delivery, and evaluation of clinical dental care, but also could establish a means of objective testing of clinical procedures.

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APPENDIX A

In the interests of clarity and brevity, Chapters 1 and 2 of this thesis (Introduction and Literature Review), are restricted to topics directly related to concepts of facial form and masticatory function. However, the application of craniometric techniques to clinical orthodontics and dentistry, has its origins in a complex of disciplines related to human form. The purpose of the following appendix is to provide more details as to how classifications of facial type have come about.

The unique features of human form have long been of interest. Historically, attention to human form has focussed primarily on visually observed morphological similarities and differences. This approach has led to the description of distinct morphological patterns. Repeated reference to such distinctions and the wealth of evidence presumed to support them, has resulted in more formal categorizations of body types and facial types. The resultant systems of classification and associated terminology have been adopted for clinical use, and further developed through this application.

Part I of this review illustrates the significance of the historical development of human observations to the theories pertaining to human form and function. Part II deals with the establishment of the currently accepted facial type classifications in orthodontics and dentistry.

I CLASSIFICATION OF HUMAN FORM

1. Body Types

The classification of human form has been an important method of appraisal for centuries. Classifications have been applied for the purposes of identification, communication, correlation, and prediction. Throughout history, human physique has been linked to personality patterns, susceptibility to disease, and physiological constitution (Lindegård, 1953). Physical characteristics impart a very strong bias in the assessment of personal qualities and ability (Tweed, 1953; Macgregor, 1970; Willmar, 1974; Stricker et al., 1979; Lansdown, 1981). Strong implications that the "disease fits the patient," have thus prevailed throughout the medical and dental literature (Draper, 1935).

General human body form is often acknowledged in orthodontics as part of the diagnostic evaluation of a patient. A number of different classification systems used to distinguish human body builds have been based on anatomical and physiological characteristics. Three extreme variants of general human body form have usually been differentiated: slender, corpulent, and stocky (Lindegård, 1953). One commonly used classification system comes from the work of Sheldon and associates (1940). In this system, the body has been assessed for type of development as follows:

Ectomorphy - a physique characterized by linearity and delicacy of structure with presence of quantitatively ectodermally derived tissues: the nervous tissue type.

Endomorphy - a physique with quantitatively endodermally derived tissues: soft roundness, and a tendency to obesity.

Mesomorphy - a physique characterized by quantitatively mesodermally derived tissues: well-developed bones, muscles and connective tissues.

2. Craniofacial Features Related to Body Type

The relationship between the shape of the human body and the shape of the head and face has long been a matter of interest and conjecture (Björk, 1955; Salzmann, 1966). Formal investigation of the observed association between body build and the shape of the skull and dentofacial structures, has been attempted in hopes of demonstrating orthodontic prognosticative value in the assessment of body build. Most of these studies have involved the making of large numbers of measurements of various body parts, and subsequently looking for correlations between these measurements. Certain dentofacial characteristic have been linked to sturdiness of the skull, for example. Individuals of extremely sturdy build are said to have larger, broader heads (Lindegård, 1953), as well as larger tooth sizes, earlier tooth eruption, and better response to orthodontic therapy due to better growth (Björk, 1955).

3. Craniometry

Historically, the recognition of head shapes has aided the study of species evolution and of ethnicity in man. Craniometry involves the integration of observations and measurements in the analysis of cranial form. Various prehistoric and modern peoples have been distinguished using the cephalic index (Kraus et al., 1959), the ratio of the maximum breadth to the maximum height of the cranium. Human averages range from seventy to ninety percent (Kelso, 1970). A low cephalic index implies a relatively long, narrow head, a condition defined as dolicocephalia, where the cephalic index equals 75.9 percent or less (Dorland, 1974). A high cephalic index on the other hand, implies a short, broad head, defined as brachycephalia, where the cephalic index is 81.0 percent or over (Dorland, 1974).

Certain populations exhibit consistent cephalic indices. Whether or not brachycephalic or dolicocephalic characteristics are inherited traits however, is not easy to determine (Kraus et al. 1959).

II FACIAL MORPHOLOGY IN ORTHODONTICS

1. Early Observations of Facial Morphology

Influenced by the craniometric studies of anthropology, orthodontists and others have studied the patterns of association between the head, the face, and the teeth. The results of many investigations have consistently shown large variations within the populations evaluated. Despite this, the establishment of a range of normal variation for human dentofacial relationships has been actively pursued. An understanding of "normal" has been assumed to be of value to the diagnosis, treatment planning, and treatment prognosis of craniofacial and dental discrepancies.

The changes in the teeth, from the anthropoids to modern man, show progressive refinement. The contemporary human races are supposed to reflect this trend as well, from the "primitive" Australian aboriginal peoples, to the "most refined" European peoples (Downs, 1938). The concept of "domestication" affecting the facial skeleton and dentitions of man was thus put forth (Downs, 1938; Björk, 1951), and was thought to be demonstrable ontogenetically in animals, as well as in the evolution of man from "primitive" to more "civilized" modes of life.

Various factors are believed to govern the growth and development of the denture, and hence also influence facial growth. Downs (1938) suggested a relationship between form and function, such that denture and facial forms were related to the stimulation of tissues by forces delivered through the teeth. He proposed that in "normal occlusion," a "close and consistent correlation between arch form, tooth form, and facial form and cephalic index" should exist. On the other hand, optimum correlations were possible only if the occlusion was normal, because only then, when the teeth were in a "correct" relationship, being used in "correct" functioning movements, could stimulation be completely efficient.

A number of dentofacial correlations to cephalic index supported Downs' beliefs. For instance, dolicocephalic people with a low cephalic index, tend to possess tapering tooth and arch forms, while brachycephalic people, with a high cephalic index, tend to possess square tooth and arch forms. Downs suggested that the inclined planes of the teeth were the dominating guides during the chewing stroke. The tendency towards more tapered teeth, and therefore more sharply inclined planes, in the dolicocephalic individual would necessitate a more vertical chewing stroke than the brachycephalic individual. Delivery of such vertical stresses to the bone by the teeth, would increase stimulation of vertical growth and decrease stimulation of lateral growth. Conversely, more square-type teeth would encourage the maximal width development of the face and the denture.

Downs (1938) also pointed out that the relative positions of the muscle origins and their direction of pull were normally closely correlated to cephalic index, and were another factor in determining arch form. The "sensitivity of the craniofacial complex" to changes in function was emphasized. How such functional influences, governed primarily by diet, affect the skeleton has been shown in the Eskimo (Downs, 1938; Hylander, 1972).

It is commonly accepted that muscle traction exerts a considerable influence on bony structures. In the early evolutionary stages, it is believed that huge muscle forces were acting on the cranial bones, causing massive excrescences at their insertions. The observed morphological differences are at least partly attributed to the functional requirements governed by the diet (Davis, 1964; Hiiemäe, 1967; DuBrul, 1972 and 1979; Noble, 1979;

Funakoshi, 1980). Bony vestiges resulting from muscle activity have been identified as being present in recent human skulls, especially in the nuchal, temporal, and gonial regions (Jensen and Palling, 1954). Although generally much reduced in modern man, their relative prominence is believed to reflect individual diet and function, hence, they have been used by researchers to gain an impression of the amount of muscle mass which the individual possessed.

2. Theories of Evolution and Growth of the Human Face

Evolutionary changes are believed to reflect changes in function and environment. The theories of evolution and growth have thus been expected to help in the understanding of modern human craniofacial form.

Since the time of our earliest human ancestor, the dentofacial complex has undergone a reduction in size. An inverse relation between the size of the brain and the size of the jaws has been postulated (DuBrul and Laskin, 1961). It seems that the evolutionary trend of the mandible in particular, has resulted in its narrowing and "weakening" (Schumacher, 1972). The gonial angle (where the ramus and body of the mandible meet) has decreased overall from an approximately flat plane in the early reptiles to approximately a right angle in the anthropoids. This has been interpreted by some (Jensen and Palling, 1954; Noble, 1973) as the effect of an intensification and differentiation of the chewing function. Conversely, the relative increase of the angle in the transition from anthropoids to man has been explained as a result of a decrease in muscle mass. With bipedal locomotion, the forelimbs were freed to develop into major feeding accessories, which greatly altered the feeding mechanics of the jaws (DuBrul, 1972).

The gonial angle may reflect functional demands in ontogenetic as well as evolutionary senses. Consider its changes with age. The gonial angle at birth is relatively obtuse, but it shows a significant decrease with age to adulthood, and generally, an increase in old age (Hellman, 1927; Jensen and Palling, 1954). This has been attributed to growth changes associated with the development and eruption of the dentition early in life, and degenerative changes associated with the break-down or loss of the dentition later on in life. Between birth and two years of age, the gonial angle is thought to be greatly affected by functional requirements for feeding (Jensen and Palling, 1954). The gonial angle increase, late in life, has been attributed to the effect of increased masseter muscle pull, necessitated by the loss of the teeth (Hellman, 1929).

The characterization of facial types often includes the gonial angle because of its apparent relationship to skull shape. Kieffer found that the gonial angle was considerably larger in brachycephalic Germans than in dolicocephalic Italians and Negroes (Jensen and Palling 1954). Many have reported similar evidence of a relationship between facial height, mandibular ramal height, and gonial angle (Hellman, 1927; Draper, 1935; Cleaver 1937; and

Sheldon *et al.*, 1940). Hrdlička (1940) however, did not find any correlation between skull type and gonial angle.

The work of many investigators has focussed primarily on the mandible with regard to its shape and relative position (Hellman, 1927; Sicher, 1947; Downs, 1948). Some have regarded growth of the mandible, especially the condylar cartilage, as the main determinant in the development of the whole face (Sicher, 1947). It has been suggested that in an individual of the stocky type, cartilaginous growth is slow, and a short but heavy ramus with a small gonial angle results. The entire facial height is secondarily reduced and the face is thus wide and short. In the tall, slender, long-limbed type of person, the opposite is predicted, such that the mandibular characteristics of a long and narrow ramus with an obtuse gonial angle result, the facial height is increased, and the resultant face is narrow and long (Sicher, 1947).

The theories of the evolution of man have been the bases for many attempts to explain facial form and the relative positions of the mandible andthe maxilla. The evolution of the present hominid head form is said to be due to three main influences acting on the "basic mammalian arrangement" (DuBrul, 1972 and 1979): changes in feeding mechanics (as previously mentioned), plus a larger brain, and erect bipedalism.

The enlargement of the cerebrum and the forward vaulting of the frontal part of the brain case, has resulted in an overall shortening of the depth of the face and an overall increase in the height of the face (Enlow and McNamara, 1973). The jaws, which in most mammalian groups lie chiefly in front of the eyes, appear to have swung downward and backward, so that in the primates they are mostly behind and beneath the eyes (Jensen and Palling, 1954; Enlow and McNamara, 1973). In hominids, the jaws are even less prominent, and the profile becomes progressively straighter in modern man (Björk, 1951).

Perhaps the most profound influence on the development of human form has been related to the shift to a vertical gait (Jensen and Palling, 1954; Mohl, 1984). This shift in overall posture, demanded a reorganization of all of the muscles, and a radical repositioning of the visceral cranium relative to the neurocranium. A severe bending of the elongate primitive skull near its middle, between visceral and neural components, thus occurred (DuBrul, 1972). The craniofacial renovations may be summarized, according to DuBrul (1972 and 1979), as follows:

1) vaulting of the dorsum
2) buckling up of the cranial base at sella turcica
3) downward and forward positioning of the nuchal plane
4) forward shift of the foramen magnum and occipital condyles
5) extreme retrusion of the snout, with shrinking and crowding of the jaws
6) deepening of the mandible and outward flaring of its entire lower border.

Attempts have been made to test the theories of evolution by simulating the adaptational influences experimentally. DuBrul and Laskin, in 1961, reported on their investigations into the preadaptive potentials of the mammalian skull. By surgically removing the spheno-occipital synchondrosis of the cranial base in rats, they produced a curvature to the cranial structures. These were identical to some of the classical changes in the skull thought to represent adaptations to an upright posture. Fanghänel (1972) investigated the influence of statics upon the postnatal development of the skull and orofacial system in rats. By surgical amputation of the front extremities at the shoulder, the growth adaptations to bipedal posture and locomotion were studied. Fanghänel reported evidence of a trend towards "brachycephalization," particularly in the dimensions of the skull characterizing length.

3. The Establishment of Criteria for Facial Type Classification

As mentioned in the previous section, the bending or flexure of the cranial base is a distinguishing feature of the hominid skull. The degree of this flexure has been studied with respect to facial morphology (Enlow and McNamara, 1973), and may be linked to other facial characteristics. In the dolicocephalic type, the cranial base is comparatively horizontal or "open," representing relatively little flexure. In contrast, in the brachycephalic type, the floor of the cranial base is said to be more upright or "closed," representing a relatively greater degree of flexure. The positions of the nasomaxillary complex and the mandible are thought to be linked to the degree of bending in the cranial floor (Figure

A.1). In the dolicocephalic type, the nasomaxillary complex is located more anteriorly and inferiorly, and the mandible is more retruded, while in the brachycephalic type, the nasomaxillary complex is located more posteriorly and superiorly, and the mandible is more protruded. Similar associations between cranial base, facial, and dental relationships have been supported by a number of investigators (Björk 1951 and 1955; Renfroe, 1948; Moss, 1955; Coben, 1955; Hopkin et al., 1968; Bishara and Augspurger, 1975).

Correlations between dental and facial characteristics are widely used as diagnostic tools in orthodontics. The "Tweed Triangle" (Tweed, 1954) for example, is a method of assessing dentofacial relations as seen in a lateral cephalometric radiograph. Such correlations have gained a sense of importance through their frequent use and widespread application.

The Tweed Triangle is formed by the Frankfort horizontal and mandibular planes, and a line passing through the long axis of the lower incisor tooth. Certain angular relationships were found to exist between these planes in cases of "normal" occlusion and "esthetic" facial form. For a given Frankfort horizontal-mandibular plane angle, a certain dental pattern would thus be required to maintain good facial form. Some degree of variation could be accommodated through compensations in the dentition or mandibular plane inclination (Tweed, 1946 and 1953).

Other commonly used dentofacial correlations concerning

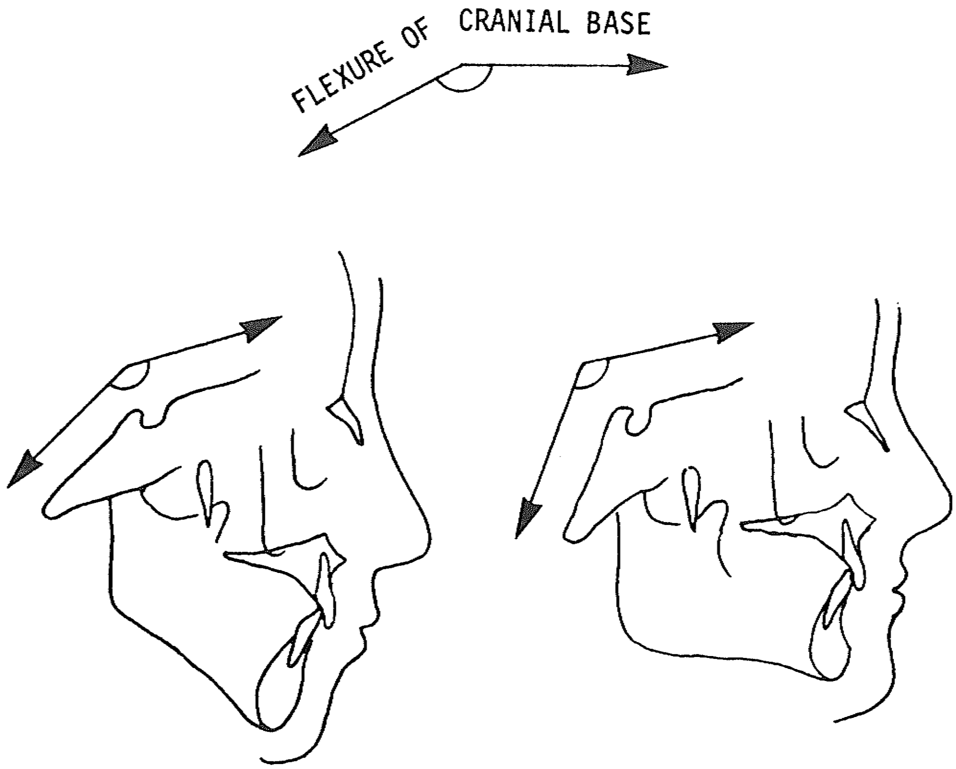

Figure A.1 DEGREE OF CRANIAL BASE FLEXURE vertical proportions have been noted (Wylie, 1945; Ballard, 1957). These observational studies have been supported by clinical experience, and have firmly established certain parameters as useful clinical tools. These parameters are supposed to provide important diagnostic clues to a more complete pattern of typical characteristics, and therapeutic cues in terms of expected responses and achievable treatment results.

Growth and Development

Many attempts have been made to discern patterns of facial growth and development in order to rationalize and predict facial types. A great deal of attention has been paid to interpreting the effects of mandibular growth on the development of the face. In what is now considered classic work, Björk (1969) used implants and serial radiographs to study growth changes in children. He concluded that two types of rotational mandibular growth, forward and backward, could take place. Many others have supported this concept and have described mandibular growth variations in terms of forward and backward rotations (Schudy, 1965; Isaacson _et al_., 1971; Isaacson _et al_., 1977).

The importance of facial typing according to growth patterns and facial morphologies has been emphasized in orthodontics. Presumably, this is because orthodontic problems could be better dealt with through an identification and understanding of the specific patterns of growth responsible for them.

The terms counterclockwise rotation and clockwise rotation have been applied in describing facial types (Schudy, 1965). These terms are based on the conventional lateral view of the head (norma lateralis), where the profile faces to the viewer's right. Rotation of the mandible is thought to result from inharmonious vertical and anteroposterior (horizontal) growth of the component parts of the mandible. The point of rotation of the mandible is thought to be located at the most distal mandibular molar in occlusal contact (Schudy, 1965).

A clockwise rotation of the mandible, is observed when relatively more vertical growth in the molar areas than in the condyles has occurred. In extreme cases, this results in an open bite. A counterclockwise rotation of the mandible is observed when more condylar growth than vertical growth at the molars has occurred. If extreme, a deep or closed bite is the result. Rationales have been sought to explain why these extremely different patterns of mandibular growth come about. Relationships reflecting compensatory growth are found between the gonial angle, MPA, and the angle formed by the occlusal plane and mandibular plane (OMA). Cases of severe vertical dysplasia, where SNMPA and OMA are very large, are often accompanied by a severe open bite, a tongue thrust, and mentalis muscle strain. It has been suggested that an imbalance between condylar growth and vertical molar growth, results in a large SNMPA, and a large gonial angle (Schudy, 1966). The chin point is thus forced away from the tip of the nose, putting a functional strain upon the integumental tissues and the tongue. This "malfunction" of the soft tissues calls for a compensatory vertical growth of the mandibular anterior alveolar process in an attempt to relieve the strain. The changes observed have been interpreted as occlusal plane compensations for "inharmonies of growth" (Schudy, 1965).

Many explanations for the observed patterns of facial growth have been described and applied. Those based on longitudinal data rather than cross-sectional data, are felt to be far superior for the evaluation of trends in facial growth (Popovich and Thompson, 1977; Bishara and Jakobsen, 1985).

APPENDIX B

TABULATED DATA FROM THE CLINICAL SAMPLE: COMPARISON OF MEASURED ANATOMICAL RELATIONSHIPS

Patient	Condyle-CA x (mm.)	2m-CA x (mm.)	Condyle-OP y (mm.)	Condyle L-R z (mm.)	M-T Angle (degrees)
Long/Steep:					
J.B.	88.5	49.5	36.5	50.0	69.0
J.W.	92.5	46.5	39.0	50.0	68.0
K.M.	92.0	44.5	27.5	44.0	68.0
P.A.	85.0	40.5	36.0	42.5	66.0
D.K.	104.5	45.0	45.0	54.0	63.0
B.P.	84.0	44.0	50.0	54.0	77.0
J.Z.	92.0	40.0	35.0	51.5	62.0
T.K.	82.5	40.5	33.0	48.0	61.0
Short/Flat:					
S.E.	86.5	44.5	41.5	52.5	68.0
D.H.	90.5	41.5	39.0	52.0	69.0
C.S.	80.0	45.5	37.0	56.0	67.0
T.W.	80.5	40.0	37.0	53.0	62.0
L.P.	85.0	45.0	38.5	49.0	71.0
P.D.	89.0	41.5	43.5	56.0	62.0
A.L.	86.5	46.5	33.5	51.5	68.5
D.M.	76.0	40.0	39.5	52.0	55.0

Where: Condyle-CA = distance along x-axis from height of condyle to central anterior position

2m-CA = distance along x-axis from second molar tooth to central anterior position

Condyle-OP = height along y-axis of condyle to occlusal plane

Condyle L-R = intercondylar distance (z-axis)

M-T Angle = angle between masseter and temporalis muscle vectors in the lateral view