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A CEPHALOMETRIC ANALYSIS OF MYOSKELETAL RELATIONSHIPS

by

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Abstract

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Throughout its evolutionary process, cephalometrics has carried with it the anatomical landmarks and measures utilized, for the most part, in physical anthropology. Because of this, cephalometric analysis still relates the relationships of skeletal components on a purely static basis rather than a dynamic one. Since the relationships between function and growth are well documented in the literature, it seems obvious that the next evolutionary step in cephalometric analysis should attempt to relate the skeletal components of the face on a much more biological basis. This study was an attempt to do so.

Cephalometric points were selected to represent the origins and insertions of various muscles and ligaments that attach to and influence the growth and displacement of some of the principal skeletal components of the craniofacial complex. Measurements were made between points to establish muscle patterns for 400 sample subjects. The sample was divided into 10 year old males, 10 year old females, 14 year old males and 14 year old females. This was done to attempt to classify and define possible subgroups that may exist in these populations.

The sample was subjected to various cluster analyses using the computer facilities of the Center for Human Growth and Development at the University of Michigan and resulted in the generation of 11 subgroups within the population of 10 year old males. A subjective evaluation was attempted as to the morphologic picture presented by the cases in each of these subgroups. The clusters were indistinct in the female population as well as the 14 year old male population, probably due to the extreme nature of variation in relationships within these populations associated with the pubertal growth spurt.

It was unexpected to find that the entire 10 year old population (males and females), when subjected to clustering, demonstrated almost totally separate groupings according to sex.

Further studies are now indicated to refine the method and to evaluate the morphologic nature of these relationships at different ages.

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DEDICATED

to

Vicki, my wife,
for her love, support
encouragement and unselfish sacrifices.

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who brighten my life.

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INTRODUCTION

Cephalometrics is a universal and valuable tool in orthodontic diagnosis and treatment planning as well as craniofacial research. Since it's inception in the 1930's, numerous methods have been devised by clinicians and researchers alike to analyze and classify the skeletal relationships of the craniofacial complex. Much discussion continues today over which analyses are the most expedient and informative and which measures and landmarks the most valid and reliable for the purpose of analysis and classification of malocclusion. The problem is well stated by Moyers (1980):

> A common problem in biologic and clinical sciences is the taxonomic one defining and labeling subgroups within a population. In orthodontics this process has been carried out traditionally by methods that are essentially subjective and, therefore, unable to deal with a whole other set of variables in an efficient, mathematically reliable way. The classic example is the Angle classification of malocclusion.

Cephalometrics, having evolved from the field of physical anthropology via craniometry and cephalometry, has inherited many, if not most of it's osteological landmarks from these other disciplines. The landmarks used to establish bony dimensions on dry skulls are still utilized today in cephalometrics to evaluate structural relationships among skeletal parts.

Perhaps much of the controversy and confusion in cephalometrics is the result of attempts to relate the skeletal components of the craniofacial complex on a purely structural (static) basis rather than a functional (dynamic) one. If form indeed follows function then many of the cephalometric points and planes we utilize today have a limited, or no, biologic basis.

The osseous components of the head are enveloped in masses of soft tissues. Muscles, nerves, glands, connective tissue, adipose, vessels and sensory organs surround and are supported by the skull. Conversely, the morphology, size and spatial relationships of the skeletal components are directly influenced by the soft tissues. With this in mind and assuming the present methods of cephalometric analysis are limited in concept, application, interpretation and usefulness in taxonomy, it is the intent of the present study to discard the usual "cephalometric analysis" bias as to the significance of contiguous osseous relationships in favor of an attempt at a more dynamic and function related analysis having a biological basis.

REVIEW OF THE LITERATURE

The literature review for this project involves two major areas of past endeavor. First, an historical overview of various attempts to classify malocclusions and second, research into the area of muscle effects on bone will be presented.

Classification Systems

Perhaps the first direct attempt at classification of malocclusion was made by Joseph Fox in 1803. His groupings were based on the labio-lingual relationship of the upper and lower anterior teeth. He subdivided these groups according to the number of teeth that assumed the malrelationship in question.

In 1819, Delabarre added terminology to Fox's classification system by establishing the terms overbite, underbite, edge-to-edge, and crossbite.

Marjolin, in 1823, proposed different terminology in terms of "maldirection" of the dental arches. He used three main classes of malocclusion:

1. Prominence
2. Recession
3. Inversion

Maury, who followed Margolin's scheme of classification of malocclusion, commented on the state of the art in 1828:

> The different configurations, both of the jaws and teeth are susceptible of many varieties which experience alone can enable us to distinguish.

Although many attempts at classification of occlusion had been made subsequently it was not until the work of Carabelli in 1844 that any advancement in classification was realized. He recognized six forms of malocclusion and introduced protrusion and retrusion of the jaws into his system. His six classes were:

1. Mordex normalis (normal bite)
2. Mordex rectus (edge-to-edge bite)
3. Mordex apertus (open bite)
4. Mordex prorsus (protruding bite)
5. Mordex retrorsus (retarding bite)
6. Mordex tortuosus (crossbite)

Although many treatises on orthodontic classification had been written subsequent to Carabelli, no acceptable method for classifying and describing the relationships of the teeth and jaws had been universally adopted until Edward Angle (1899) published his classification system in Dental Cosmos. Angle described three basic types of malocclusion based on deviations in an anteroposterior dimension using the relationship of the upper and lower first molars as an index.

Calvin Case (1921) pointed out that Angle's classification was severely limited in scope in that it did not take into account the relationship of the teeth to the face as well as the three-dimensional aspect of many malocclusions.

Simon (1926) developed a system called "Gnathostatics" which, although complex, allowed for analysis in three dimensions by relating the teeth to the face as well as the cranium. He oriented plaster casts of the dental arches to the face by trimming the base of the maxillary case parallel to the Frankfort horizontal plane so that the occlusal plane on the casts established the same angular relationship to the base as the natural occlusal plane had to the Frankfort horizontal plane of the patient proper. Simon claimed that in normal occlusions, the perpendicular from the Frankfort horizontal plane at orbitale (the orbital plane) passed through the distal third of the maxillary canine. He categorized anteroposterior discrepancies by their relationship to the orbital plane.

With the introduction of cephalometrics into orthodontics made possible by Broadbent (1931) the investigator was then able to view, radiographically, the relationship of the skeletal parts of the face to the teeth and to each other. It was then possible to differentiate, with relative ease, between dentoalveolar and skeletal discrepancies and thus negating a major limitation of the Angle classification system.

Following Broadbent's classic work, investigators began to devise methods of measuring the skeletal components of the head, in vivo, and analyzing their relation to one another and to the dental arches. Approximately ninety such analyses had been devised,

as reported by Krogman and Sassouni (1957), during the period between 1931 and 1956. Many of these analyses attempted to add a skeletal assessment to the Angle system of classification.

A basic problem involved with classification using the Angle system was stated by Ackerman and Proffit (1969):

> This difficulty becomes apparent when it is recognized that malocclusions having the same Angle classification may indeed, be only analogous malocclusions (having only the same occlusal relationships) and not necessarily homologous (having all characteristics in common). Despite the informal additions to Angle's system which most orthodontists use, there is a tendency to treat all malocclusions of the same classification in a similar manner. Homologous malocclusions require similar treatment plans, whereas analogous malocclusions may require different treatment approaches.

Ackerman and Proffit (1969) developed a system of classification based on five descriptive characteristics which they felt overcame the major weaknesses of the Angle system. They analyzed a case by:

1. Analysis of the alignment and symmetry of the teeth in the dental arches.
2. Analysis of the patient's profile.
3. Analysis of lateral dimensions of the dental arches and buccolingual relationships of the posterior teeth.
4. Anteroposterior relation of the dental arches utilizing the Angle system with additions for skeletal, dental or combination deviations.
5. Analysis of vertical dimension.

Using these characteristics they described nine groups of malocclusions using a modified Venn diagram. The groups were

ranked according to the complexity of the orthodontic problem. They felt that this method of classification had, inherent in it, a diagnosis.

Sassouni (1955, 1969) developed a classification of skeletal facial types utilizing the "archial analysis." He divided certain skeletal relationships into eight different groups depending on the anteroposterior and vertical components of a dysplasia. He utilized the Angle classification to describe the anteroposterior relationship, and "deep bite" and "open bite" to describe the vertical.

Hitchcock (1969, 1973, 1976) presented a cephalometric description of Class I, Class II Division 1, and Class II Division 2 malocclusions. In analyzing Class II Division 1 malocclusions he compared 109 cases with 40 normal occlusion cases according to the "Alabama Analysis." He found that the SNA measurement was not significantly different between the two groups. The SNB measurement was smaller in Class II Division 1 malocclusions, and the resultant ANB angle was greater. He also observed the facial plane (NP) to SN measure to be smaller in Class II Division 1 cases while the Y axis angle was increased.

In a subsequent study comparing Class II Division 2 malocclusions to Class II Division 1 and the control samples, Hitchcock (1976) again found no significant differences between SNA angle measures. He found only slight SNA-SNB differences. He

observed the AB to occlusal plane angle to be a more distinguishing measure in Class II Division 2 as was the case with Division 1 malocclusions. Hitchcock concluded that Class II Division 2 malocclusion was probably not a significant clinical syndrome within itself.

Lavelle (1977) contrasted lateral cephalograms of individuals with Angle Class I, Class II and Class III malocclusions in order to assess the varying relationship of the skeleton in each occlusal category. He used fourteen linear and fourteen angular measurements. Univariate statistical analysis showed varying contrasts between the classes depending on which dimensions were compared. Multivariate analysis of all the measures combined revealed significant contrasts between the classes. He concluded that only with multivariate statistical analysis can the intricacies of the craniofacial complex be interpretated and therefore, classified.

Hirschfeld et al. (1973) developed a method of deriving subgroups within the Angle classification rather than comparing the existing classes. Using lateral cephalograms of 308 North American white children age six to eighteen years, they subjectively evaluated the skeletal malocclusion according to Angle's classification system. By utilizing two methods of multivariate "clustering" they derived five groups that showed some resemblance to the Angle classes. They discovered that Class III malocclusions

could be clustered quite distinctly and that there were probably two subgroups within Class III, differentiated by the nature of the anatomic imbalance. The relationship between Class I and Class II was less distinct. However, there was enough evidence to conclude that the Class II category contains at least three subgroups.

Moyers et al. (1980), in a subsequent work, attempted to further identify and define subgroups within the Angle Class II classification. They used 697 lateral cephalograms of North American white children who had undergone treatment for a Class II malocclusion or were untreated. Using multivariate analyses, cluster analyses and discriminate functions, they described 6 horizontal and 5 vertical subgroups within the Class II sample. There appeared to be a strong relationship between horizontal and vertical facial types allowing identification of 15 subgroups within the Class II population.

Muscle Effects on Bone

The predominant concept of facial growth control today has been generally labelled the Functional Matrix Theory. Conceived by van der Klaauw (1946) this theory has since received extensive study and refinement by Moss (1960, 1962, 1968, 1969, 1971, 1972) and many others. van der Klaauw proposed that:

> The skull may be regarded as a complex of relatively separate functional components, sometimes detached, sometimes united in a morphological whole, but even in this case to a certain extent independent in size, relative position and grouping.

In review of the postulates of the functional matrix theory, Moss states that every function is carried out by a "functional cranial component," each component consisting of two parts: a functional matrix which actually carries out the function and a skeletal component whose biomechanical role it is to protect and support its specific functional matrix. He divides the functional matrices into two types. The first is the periosteal matrix, which acts directly on the skeletal units by stimulating osseous deposition and resorption, thereby altering the size and morphology of the unit. The periosteal matrix includes muscles and the teeth. The second is the capsular matrix, which acts on the skeletal units as a whole and effects a passive translatory shift in spatial relation. The translation occurs secondary to the expansion of the central, encapsulated volumes (capsular functional matrices) such as the brain, eyeball and functional spaces (nasal, oral, pharyngeal, etc.).

The growth effects of these functional matrices, particularly the muscular component, on the size, shape and spatial relationship of the skeletal units is well documented in the literature.

Washburn (1947) has shown a direct influence on the form of the skull and coronoid process of the mandible by the temporal

muscle. He demonstrated, in rats, that lack of temporal muscle influence produced an asymmetry of the skull when the muscle was transected unilaterally. There was a lack of development of the temporal line as well as the coronoid process on the side having muscle transection.

Boyd et al. (1967) removed the temporalis muscle attachment, unilaterally in guinea pigs, at it's origin. This was done to decrease or eliminate muscle tension while maintaining the blood supply to the coronoid process. They found, in the majority of the experimental animals, no changes in the coronoid process when compared to controls. They concluded that the necessity for muscle tension in the maintenance of bony processes was in question and that perhaps loss of blood supply, in experiments where the muscle was removed at its insertion, was responsible for the decrease in size of the coronoid process.

Horowitz and Shapiro (1955) removed the masseter muscle unilaterally in 9, 30 day old rats and bilaterally in 3 animals. Comparison against controls of the same litters showed gross modifications in morphology of the skull, including the mandible and dental arches, in those animals with unilateral masseterectomy. The sweep of the zygomatic arch was considerably reduced on the operative side. The entire arch was closer to the cranium, and the zygomatic bone was exceedingly thin. The body of the mandible on the operative side bent sharply downward and laterally. The

angular process was blunt and deflected medially. The mandible on the operative side was reduced in size, especially in the superior-inferior dimension of the ramus. There was also a resultant open bite in the molar area on the operated side.

Nanda et al. (1967) surgically repositioned the masseter muscle 5 mm anteriorly at it's insertion on the corpus of the mandible in dogs. The result showed a lateral sweep of the body of the mandible between the first and second molars on the operated side. The antegonial notch was either absent or very shallow compared to the normal side. The angular process was short and less massive, showing a slight medial deflection. The distance from the angular process to the condyle was shorter by an average of 4 mm on the unoperated side. There was a slight deviation of the snout toward the operated side at the level of the first premolar.

With the advent of electromyography, it became feasible to study relationships between muscle function and facial morphology. Ingervall and Thilander (1974) studied the activity of the anterior and posterior parts of the temporal muscle, the masseter and the upper lip and their relationships to facial morphology in the human head. They made electromyographic recordings with the mandible in postural rest position, and during swallowing, chewing and maximal bite. Facial morphology was studied using lateral cephalograms of the same subjects. They found clear correlations

between muscle activity and mandibular morphology and positioning during chewing and maximal bite. During these functions the amplitudes of temporal and masseter muscle actions were large in cases with a tendency to parallelism between the jaw bases, and between the mandibular plane. These cases were characterized by a rectangular shape to the face in profile and a relatively small lower face height.

Moyers (1949), in an attempt to determine the etiology of Class II Division 1 malocclusions, used electromyography to analyze facial and masticatory muscle activity in individuals with such a dysplasia. He placed electromyographic electrodes in the temporalis, masseter, internal pterygoid, suprahyoid and mentalis muscles of 16 individuals with Class II Division 1 malocclusions and compared the muscle activity to muscle functioning patterns of 31 cases with "ideal" dentofacial morphology.

Prior to the onset of electromyographic analysis the sample was arbitrarily and subjectively classified into 4 groups:

1. total mandibular retrusion
2. mandibular dental retrusion
3. total maxillary protrusion
4. maxillary dental protrusion.

The results of electromyographic analysis also divided the subjects into 4 groups, based on muscle activity, that loosely corresponded to the original arbitrary groupings. The first group

showed normal electromyographic patterns in all muscles except the temporalis, which showed increased activity in the posterior fibers when the mandible was in physiologic rest position. These cases were the same previously identified as exhibiting total mandibular retrusion.

The subjects in the second group differed from the previous one in that the posterior temporal fibers exhibited greater spike potentials in all mandibular movements. These cases showed a strong tendency toward increased overbite.

Individuals in the third group exhibited only slight activity in the anterior temporalis fibers as well as a marked increase in activity of the mandibular elevators. These cases exhibited extreme overbite.

The fourth group presented normal pterygoid and masseter muscle activity with normal temporalis activity in all but one case. The mentalis muscle was hypertrophied in all cases, and all showed anterior open bite and presented with a history of thumb-sucking or tongue thrust.

It is interesting that the groupings derived by electromyography corresponded to the arbitrary classification. Moyers concluded that deviation from normal muscle contraction may indeed be an etiologic factor in the formation of Class II Division 1 malocclusions. He also concluded that physiologic rest position is an expression of the functioning length of all the muscles of the "temporomandibular articulation."

Cephalometric Limitations

The limitations of current cephalometric methods for analysis of the craniofacial complex have been recognized for years. Having evolved "from craniometry to cephalometry to radiographic cephalometry" (Krogman and Sassouni, 1957) most of the current cephalometric methods are based on points, planes and measures that have no biologic basis. Moss (1971) states: "Numbers are only as biologically valid as the ability of the measurements (lines, angles, etc.) to represent what is actually growing." The primary criteria in craniometry and cephalometry was that a point of reference be identifiable and reproducible. This is probably adequate for adult dry skull analysis, but cephalometric evaluations introduce another parameter called growth, which is modified by the functional forces placed upon it.

Biederman (1954) did a study appraising cephalometric norms and their validity in orthodontic diagnosis. Using pre and postoperative Downs' values from lateral cephalograms of 5 surgically treated Class III patients, he found that the "profound and favorable" changes as a result of successful surgical treatment were not reflected adequately, consistently or reliably in changes in value of the Downs' measures.

Salzmann (1964) stated:

> The validity of most cephalometric analyses in current use has not been substantianted. Lines, planes, and angles employed in cephalometric analyses are subject to modification by growth and development of the individual bones

over which they are drawn.

Kraus et al. (1959), in a study of heredity and its effects on the craniofacial complex, subjected monovular and diovular triplets to standard cephalometric analysis. Although the SNA angles were identical, there appeared to be significant differences between the other angles and measurements. This is further evidence that current cephalometric methods are of questionable value, especially in terms of taxonomy. If individuals with almost identical facial morphology present different cephalometric pictures, when viewed via current analytical methods, then we must question the methodology.

STATEMENT OF THESIS

It is the purpose of this study to evaluate some of the relationships among skeletal components of the face by analyzing the collateral relationships of various muscles, muscle groups and ligaments that directly affect the growth and displacement of the osseous components of the craniofacial complex. Further, relationships discerned by this method will be investigated in regard to their applicability to taxonomic attempts to describe craniofacial (and thus malocclusion) subgroups within a population.

Measurements will be made between cephalometric landmarks selected to represent the origins and insertions of various muscles and ligaments that have been shown to, or are suspected of having, an influence on the morphology and spatial relationships of some skeletal components of the face. These data will be subjected to multivariate (cluster) analysis in an attempt to derive subgroups within the population sample.

METHODS AND MATERIALS

Source

The lateral cephalograms utilized in this study were provided by the Bolton-Brush Foundation of Case Western Reserve University.

Normative Sample

For purposes of this study it was necessary to establish a baseline for sample comparison. This normative sample was taken from the cephalograms used to derive the Bolton Standards. Sixteen males and sixteen females were selected and their lateral cephalograms at age 10 years and 14 years were used. These ages were selected because they are generally considered to be at extreme and opposite ends of the adolescent growth spurt which generally occurs between the ages of 10 and 12 years in the female and 12 and 14 years in the male.

Sample

A sample of 400 lateral cephalograms was selected from the general records of the Bolton study. They consisted of 100 males at age 10 and 14 years and 100 females at the same ages. The selection was random except for the following criteria:

1. Each individual had a cephalogram at age 10 and 14 years.

2. No orthodontic treatment had commenced prior to taking the 14 year cephalogram.

3. The quality of the cephalogram was adequate for landmark identification.

Point Selection

The landmarks were selected to represent the origins and insertions of the following muscles, muscle groups and ligaments:

1. masseter muscle
2. medial pterygoid muscle
3. lateral pterygoid muscle
4. buccinator and obicularis oris muscles
5. temporalis muscle
6. sphenomandibular ligament
7. stylomandibular ligament

Identification of the muscle origins and insertions on the lateral cephalogram was accomplished by outlining their anatomic limits on 3 dry skulls using 5 ampere lead fuse wire and taking lateral cephalograms of the "wired" skulls. Gray's anatomy was used to establish the anatomic limits of the muscle origins and insertions. Figures 1-6 illustrate the origin and insertions of the muscles and ligaments in question. Using these cephalograms, anatomic landmarks (points) were selected to represent the muscle origins and insertions. Figures 7-12 illustrate these points, and Tables I-VI define the landmarks.

Figure 1. Masseter muscle--origins and insertions

Superficial Portion
Origin: Arises from the zygomatic process of the maxilla, and from the anterior two-thirds of the inferior border of the zygomatic arch.

Insertion: inserted into the angle and inferior half of the lateral surface of the ramus of the mandible.

Deep Portion
Origin: arises from the posterior third of the inferior border and from the whole of the medial surface of the zygomatic arch.

Insertion: inserts into the superior half of the ramus and the lateral surface of the coronoid process of the mandible.

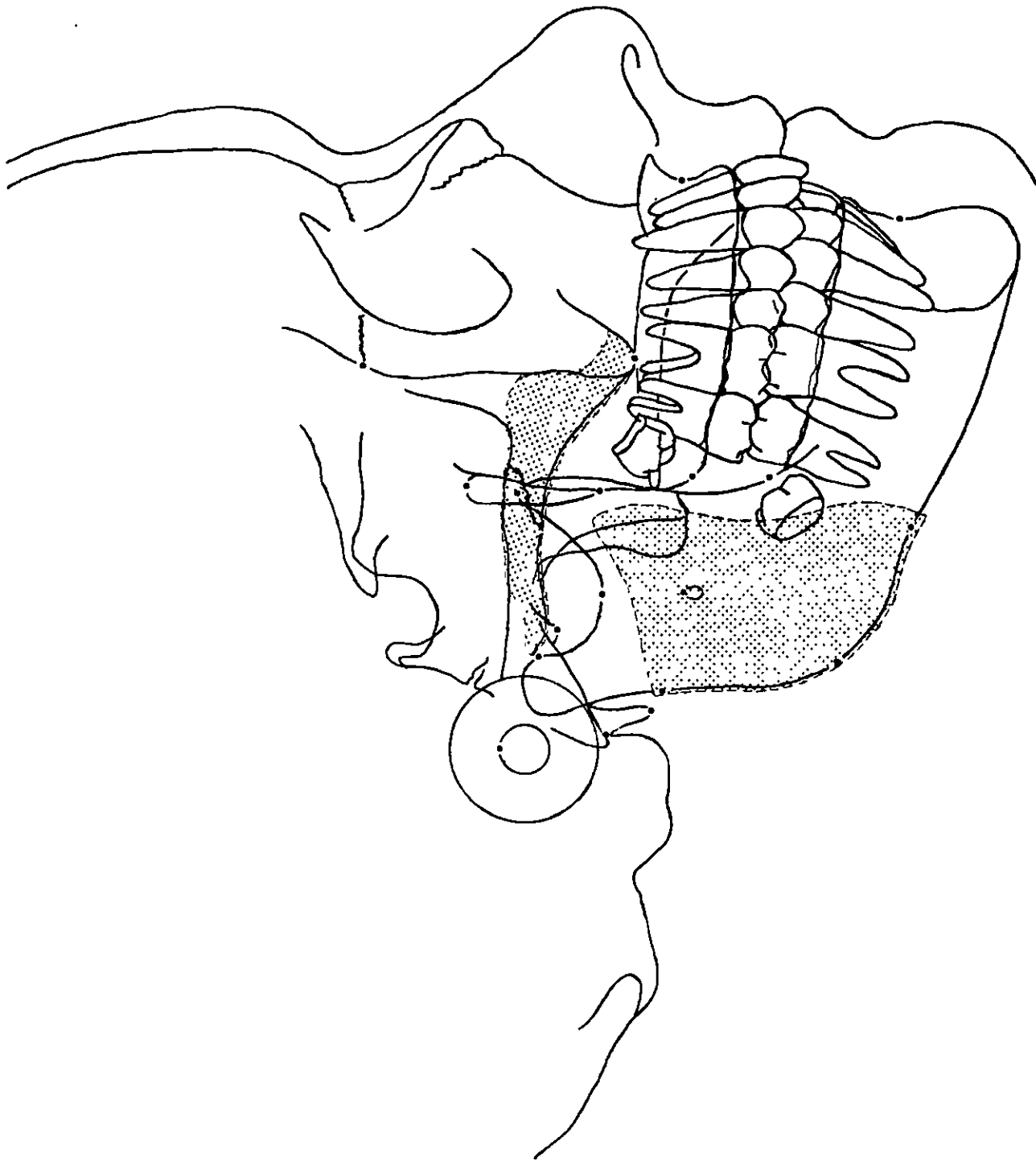


Figure 2. Medial pterygoid muscle--origin and insertion

Origin: arises from the medial surface of the lateral pterygoid plate and the grooved surface of the pyramidal process of the palatine bone: it has a second slip of origin from the lateral surfaces of the pyramidal process of the palatine and tuberosity of the maxilla.

Insertion: inserts into the inferior and posterior part of the medial surface of the ramus and angle of the mandible.

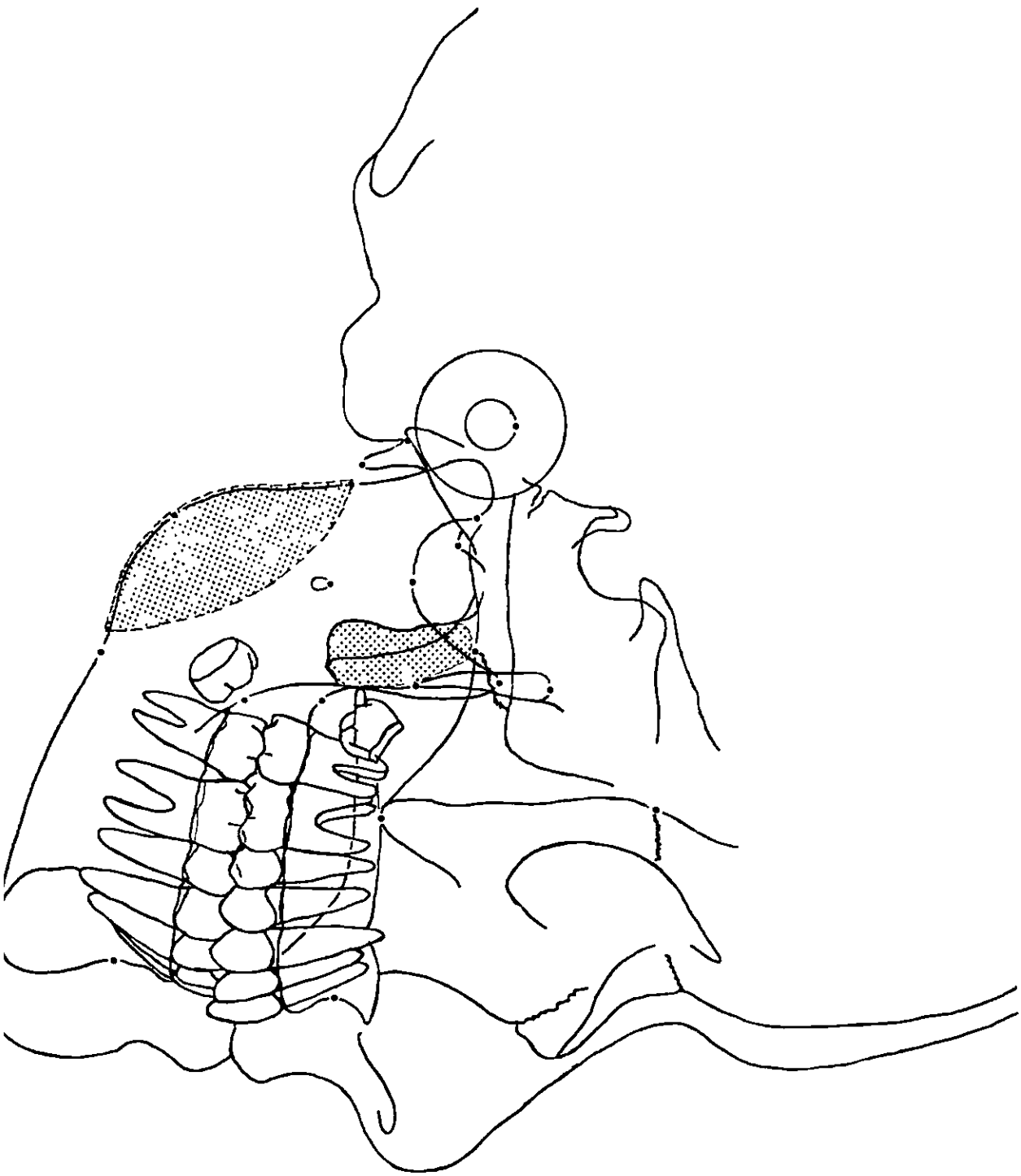


Figure 3. Lateral pterygoid muscle--origin and insertion

Origin: arises by two heads: a superior from the inferior part of the lateral surface of the great wing of the sphenoid and from the infra-temporal crest; an inferior from the lateral surface of the lateral pterygoid plate.

Insertion: inserts into a depression in the anterior part of the neck of the condyle of the mandible and into the anterior margin of the articular disk of the temporomandibular joint.

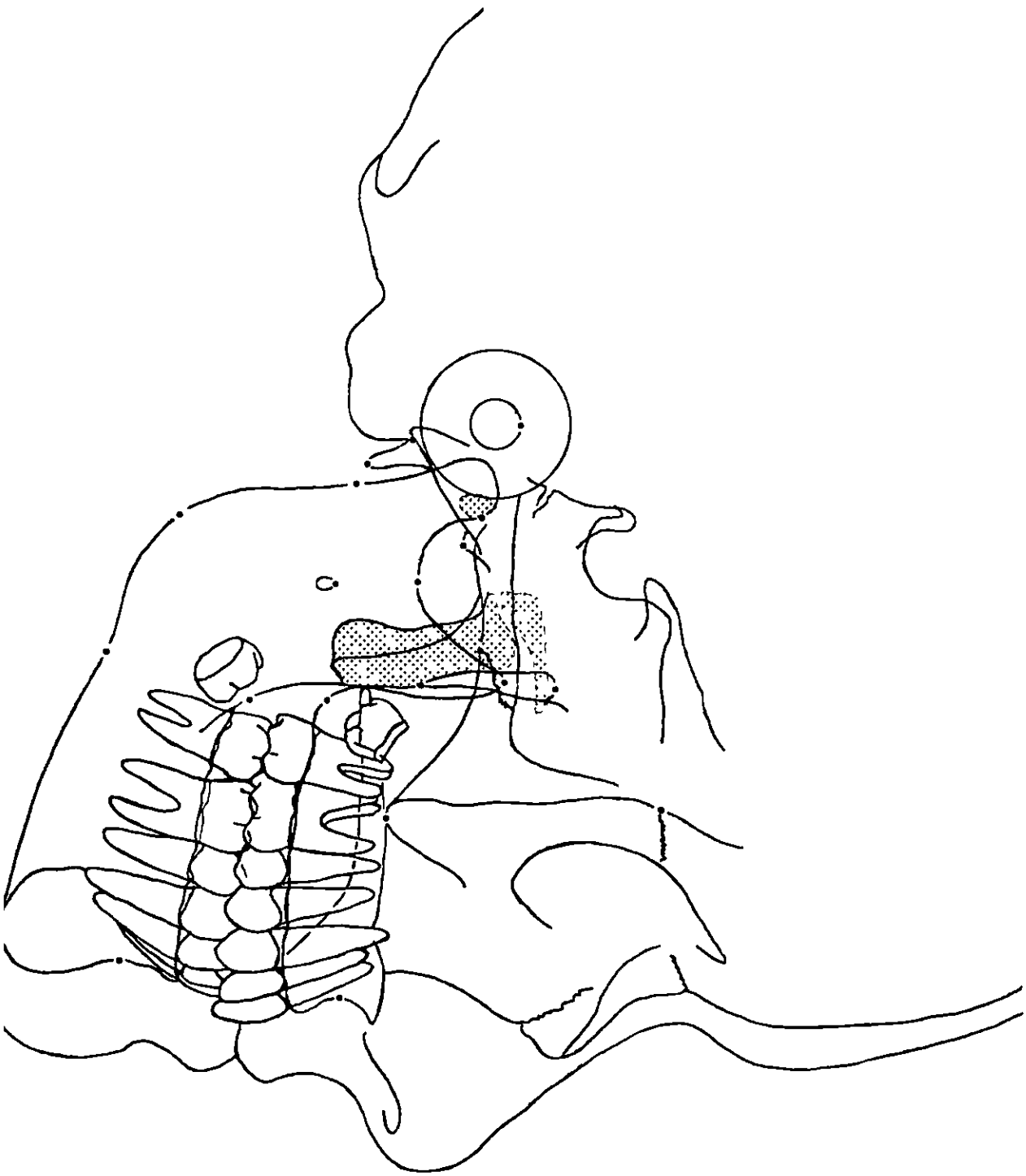


Figure 4. Buccinator and obicularis oris muscles--origins and insertions

Buccinator
Origin: arises from the outer surfaces of the alveolar processes of the maxilla and mandible alongside the three molar teeth, and in between, from the pterygomandibular raphe.

Insertion: inserts by blending into the deeper fibers of the obicularis oris muscle.

Obicularis Oris
Origin: arises from the decusation of the fibers of the buccinator and from fibers of the other facial muscles.

Insertion: inserts into the maxilla at the base of the alveolar bone beneath the nasal septum via the incisivus labii superious and the nasolabialis and into the mandible by the incisivus labii inferious, just lateral to the midline at the base of the alveolar bone.

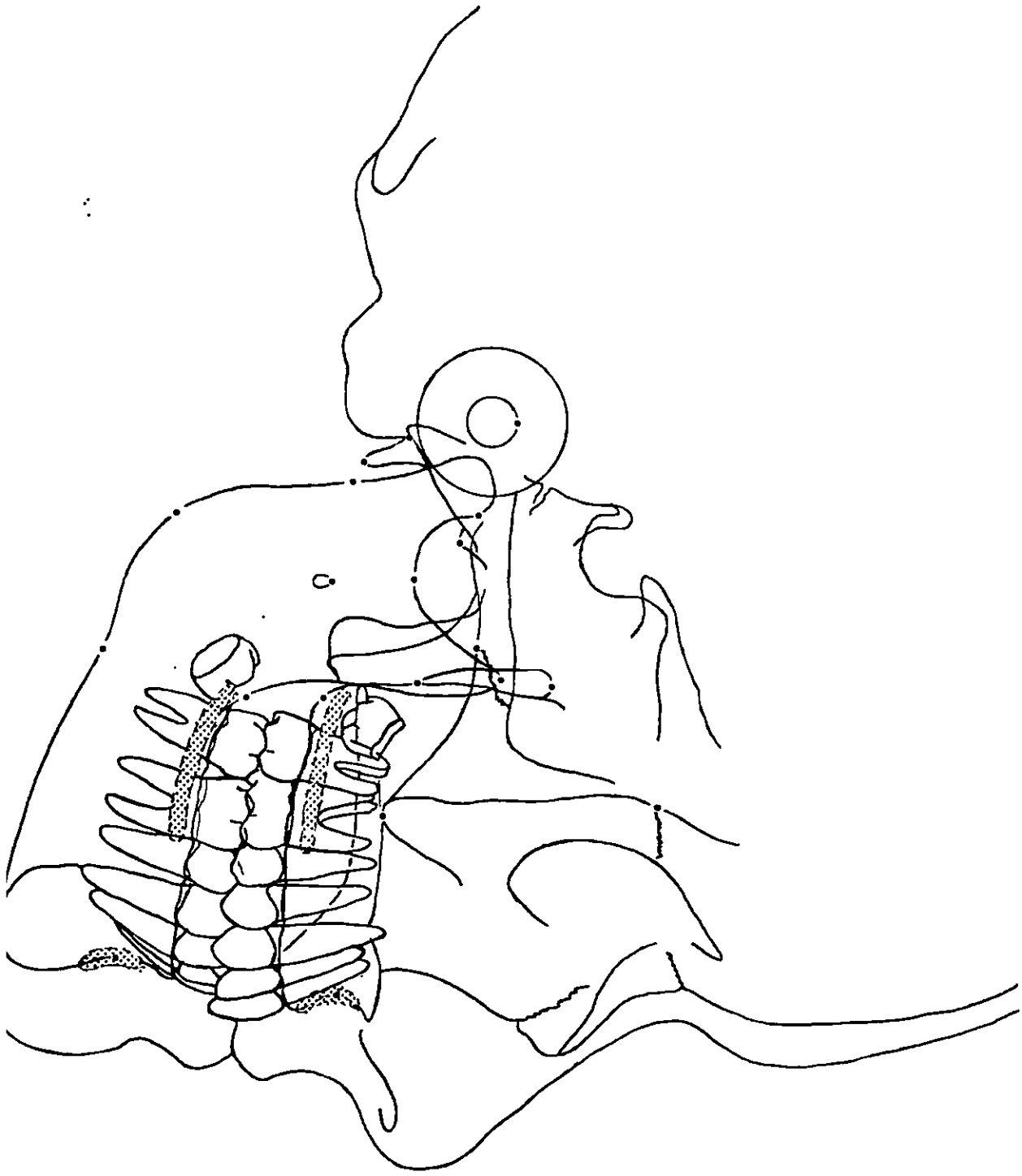


Figure 5. Temporalis muscle--origin and insertion

Origin: arises from the whole of the temporal fossa from temporal lines to infratemporal crest and from the deep surface of the temporal fascia.

Insertion: inserts into the medial surface, apex and anterior border of the coronoid process, and anterior border of the ramus nearly as far as the last molar tooth.

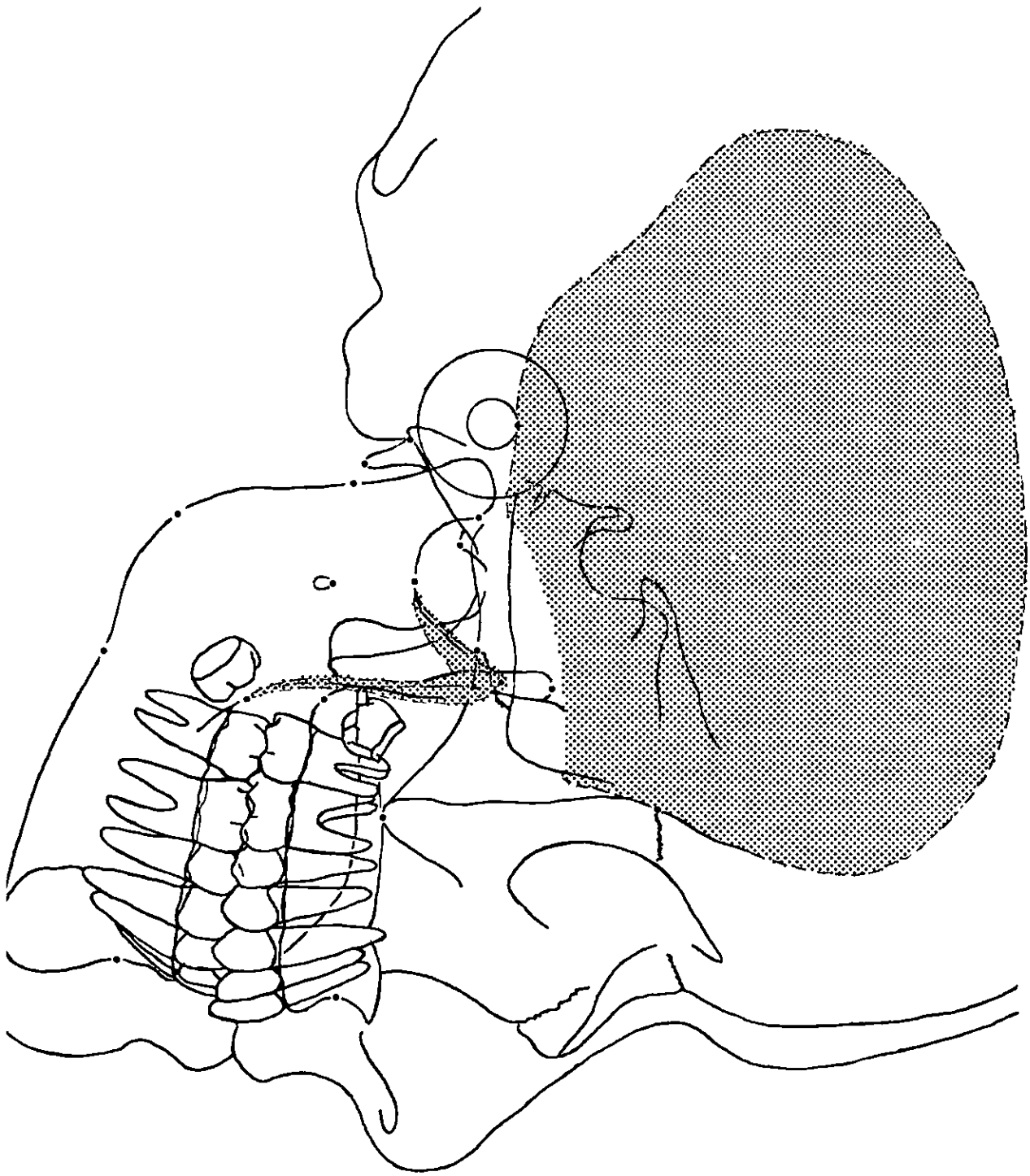


Figure 6. Stylomandibular and sphenomandibular ligaments--origins and insertions

Sphenomandibular
Origin: arises from the apex of the styloid process of the temporal bone.

Insertion: inserts into the angle and posterior border of the ramus.

Stylomandibular
Origin: arises from the spine of the sphenoid bone.

Insertion: inserts into the lingula of the mandibular foramen.

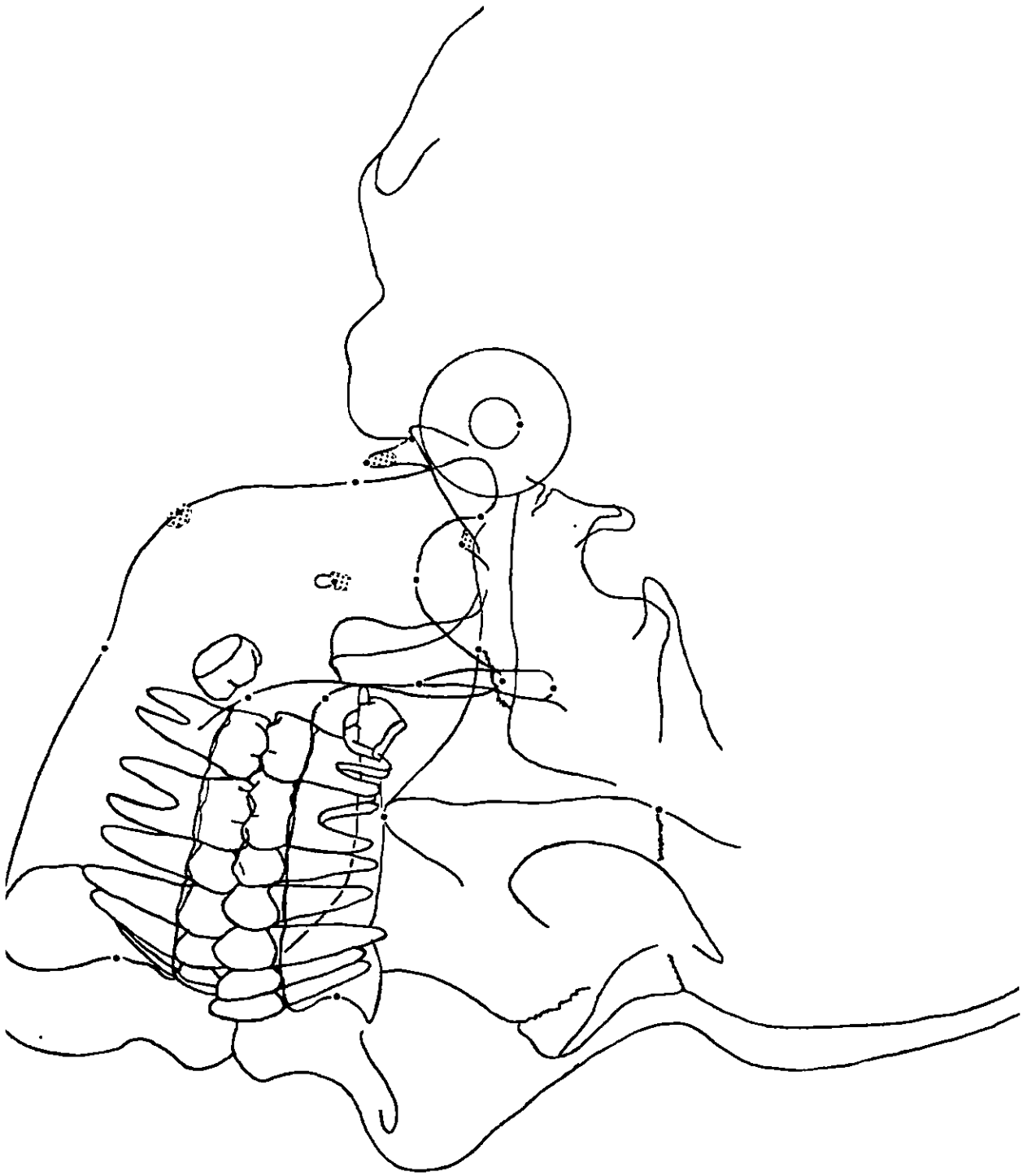


TABLE I

DEFINITION OF ANATOMICAL LANDMARKS

FOR THE MASSETER MUSCLE

Landmarks	Definition
ZT	The point at which the zygomatico-temporal suture meets the inferior border of the zygomatic arch.
KR	Key ridge--the lowermost point on the bony ridge (seen on the lateral cephalogram as a double line coming down from the temporal fossa and going up anteriorly toward orbitale) situated between the maxillary tuberosity and the canine fossa.
PR	Posterior ramus--the most anterior point on the concave curve of the posterior border of the ramus of the mandible.
Go	Gonion--the point of intersection of the gonial contour and the bisectrix of the angle formed by the ramal and mandibular planes.
AGo	Antegonion--the highest point on the concave curve of the inferior border of the lateral aspect of the mandible.

Figure 7. Masseter muscle--landmarks and measures

PR
Go
1
2
3
AGo
4
ZT
KR

TABLE II

DEFINITION OF LANDMARKS FOR THE

MEDIAL PTERYGOID MUSCLE

Landmarks	Definition
SPTM	Superior pterygomaxillary fissure--the most superior aspect of the pterygomaxillary fissure.
IPTM	Inferior pterygomaxillary fissure--the most inferior aspect of the pterygomaxillary fissure.
MT	Maxillary tuberosity--the most posterior inferior point on the maxillary tuberosity.
PR	Posterior ramus--the most anterior point on the concave curve of the posterior border of the ramus of the mandible.
Go	Gonion--the point of intersection of the gonial contour and the bisectrix of the angle formed by the ramal and mandibular planes.
AGo	Antegonion--the highest point on the concave curve of the inferior border of the lateral aspect of the mandible.

Figure 8. Medial pterygoid muscle--landmarks and measures

PR
Go
6
7
8
5
AGo
9
SPTM
IAM
MT
IPTM

TABLE III

DEFINITION OF LANDMARKS FOR THE

LATERAL PTERYGOID MUSCLE

Landmarks	Definition
SPTM	Superior pterygomaxillary fissure--the most superior aspect of the pterygomaxillary fissure.
IPTM	Inferior pterygomaxillary fissure--the most inferior aspect of the pterygomaxillary fissure.
MT	Maxillary tuberosity--the most posterior inferior point on the maxillary tuberosity.
ACor	Anterior condyle--the most anterior point on the head of the mandibular condyle.

Figure 9. Lateral pterygoid muscle--landmarks and measures

AC
10
11
12
SPTM
IPTM
MT

TABLE IV

DEFINITION OF LANDMARKS FOR THE BUCCINATOR

AND ORIBULARIS ORIS MUSCLES

Landmarks	Definition
MT	Maxillary tuberosity--the most posterior inferior point on the maxillary tuberosity.
IA	Internal angle--the point of intersection of the bisectrix of the anterior ramal plane and the plane formed by the superior aspect of the mandibular corpus with the inner curve of the mandible.
A	Subspinal--the deepest midline point on the premaxilla between anterior nasal spine and prosthion.
B	Supramentale--the deepest midline point on the mandible between infradentale and pogonion.

Figure 10. Buccinator-obicularis oris--landmarks and measures

C
MT
IA
13
15
16
14
A
B

TABLE V

DEFINITION OF LANDMARKS FOR THE

TEMPORALIS MUSCLE

Landmarks	Definition
Fmt	Frontomalare temporale--a point at the posterior or temporal termination of the fronto-zygomatic suture.
Po	Porion--the midpoint on the upper edge of the porus acusticus externus located by means of metal rods on the cephalometer.
Cor	Coronion--the most superior point at the tip of the coronoid process of the mandible.
b	the most inferior point in the notch between the mandibular condyle and the coronoid process.
IA	Internal angle--the point of intersection of the bisectrix of the anterior ramal plane and the plane formed by the superior aspect of the mandibular corpus with the inner curve of the mandible.

Figure 11. Temporalis muscle--landmarks and measures

Po
18
b
20
19
IA
21
Cor
17
Fmt

TABLE VI

DEFINITION OF LANDMARKS FOR THE SPHENOMANDIBULAR AND STYLOMANDIBULAR LIGAMENTS

Landmarks	Definition
SS	Sphenoidal spine--the most inferior point on the spine of the sphenoid bone.
MF	Mandibular foramen--the most superior point on the mandibular foramen.
St	Styloid--a point on the tip of the styloid process.
Go	Gonion--the point of intersection of the gonial contour and the bisectrix of the angle formed by the ramal and mandibular planes.
XSt	The most anterior superior point on the occipital condyle.

Figure 12. Sphenomandibular and stylomandibular ligaments--landmarks and measures.

XSt
24
St
A
Go
23
xSS
22
MF

Technical Details

The lateral cephalograms for all subjects used in this study were obtained using a Broadbent-Bolton cephalometer. Tracings were made, as necessary for location of landmarks, and points were placed on .003" acetate with a Pentel (0.3 mm) medium soft lead pencil.

Measurements

The required points were digitized and the measurements made using the computer facilities at the Center for Human Growth and Development of the University of Michigan. A summary of the measurements is contained in Table VII, while graphic representation is illustrated in Figures 7-12.

Ten cephalograms from each sex and age group were randomly selected and points were again placed and measurements made to compute correlation coefficients between these and previous measures. This was done for the purpose of evaluating the error involved with point identification and measurement.

Data Reduction

The means and standard deviations were computed for all absolute values of the normative sample. The random sample measures were then converted to Z scores utilizing the mean and standard deviation values derived from the normative sample according to the formula:

TABLE VII

SUMMARY OF MEASUREMENTS

Muscle	Measure Number	Points
Masseter	1	ZT-PR
	2	ZT-Go
	3	KR-Go
	4	KR-AGo
Medial Pterygoid	5	SPTM-PR
	6	SPTM-Go
	7	IPTM-Go
	8	MT-Go
	9	MT-AGo
Lateral Pterygoid	10	SPTM-ACor
	11	IPTM-ACor
	12	MT-ACor
Buccinator-Obicularis Oris	13	MT-IA
	14	MT-A
	15	IA-B
	16	A-B
Temporalis	17	Fmt-Cor
	18	Cor-Po
	19	Fmt-Cor-Po (Angular)
	20	b-Cor
	21	IA-Cor
Sphenomandibular (ligament)	22	SS-MF
Stylomandibular (ligament)	23	St-Go
	24	XSt-Go

$$Z = \frac{X-\bar{X}}{S.D.}$$

The Z score values were plotted for each individual in the sample in order to derive a graphic representation or muscle pattern profile for comparison between individuals. Attempts were made to visually cluster the sample into groups according to the similarity or dissimilarity of the pattern profile. The data clustered into approximately 40 groups, 4 or 5 of which contained between 3 to 7 individuals. A comparison of cephalograms within these larger clusters showed basic similarity in skeletal morphology, but the differences between groups was difficult to discern.

In order to refine the clustering procedure, all cases were subjected to cluster analysis utilizing the Michigan Interactive Data Analysis System (MIDAS). The arithmetic average clustering method was utilized. This computes the arithmetic average of similarity coefficients between a case that is a candidate for admission into a cluster and members of an existing cluster or between members of 2 clusters that are about to fuse. The measure of similarity (distance) used was the product moment correlation coefficient (r). This measures the distance between the "data profiles" derived by the collection of variables observed for a pair of cases according to the formula:

$$r_{jk} = \frac{\sum_{i=1}^{n} (x_{ij} - x_j)(x_{ik} - \bar{x}_k)}{\sqrt{\sum_{i=1}^{n} (x_{ij} - x_j)^2 \sum_{i=1}^{n} (x_{ik} - \bar{x}_k)^2}}$$

At the start of the clustering procedure each case is a cluster within itself. At each step a new cluster is formed by combining 2 clusters. This procedes in a stepwise fashion until all cases are "forced" into one cluster forming a "heirarchial tree." Subjective evaluation is then made as to the division between clusters based on the r values.

The data was clustered using 16 computer commands. The first 4 commands generated 4 groups of clusters based on age and sex (i.e., 10 year old males, 10 year old females, 14 year old males, 14 year old females). The next 2 commands resulted in 2 groups of clusters differentiated on the basis of sex (10 and 14 year old males, 10 and 14 year old females). This was done to determine if the same individuals clustered together at both ages. The next 2 commands separate the cases on the basis of age (10 year old males and females, 14 year old males and females). This was done to determine if the males and females would cluster together. The next four commands generated 4 groups of clusters similar to the first 4 commands except that it took into account the measurement error as determined by the correlation coefficients computed earlier. Finally the data for 14 year old males were clustered by muscle using the masseter, medial pterygoid, lateral pterygoid and temporalis. This was done to determine if one muscle was more reliable than another for purposes of classification. Once the clusters were established the cephalograms were then reviewed to

determine which morphological entities "define" the particular subgroups.

RESULTS

Normative Data

Table VIII lists the mean and standard deviation values for the measures taken on the lateral cephalograms of the male cases in the normative sample. Table IX lists the means and standard deviations for the females. These are the values used to convert the absolute measures, of the sample population, to Z scores.

Error Study

Table X is a listing of correlation coefficients among measures. A random sample of 40 cephalograms was selected from the sample population, and all landmarks were identified and measures taken a second time, in order to derive coefficients of correlation. These values represent the degree of error in their respective measures.

Pattern Profiles

Figures 13 and 14 are examples of the computer generated plots (pattern profiles), for 2 cases, in the visual clustering technique described earlier. This was performed for all 400 cases. By comparing the patterns as to direction of the "wiggles", the degrees of similarity or dissimilarity among the cases can be discerned. In the example shown, although the patients are from

TABLE VIII

MEAN AND STANDARD DEVIATION VALUES

FOR MALES IN THE NORMATIVE SAMPLE

	Age 10		Age 14	
Measure	Mean	S.D.	Mean	S.D.
1	33.65	2.30	34.52	3.24
2	48.07	2.78	52.80	4.73
3	56.32	2.95	60.71	2.87
4	49.65	3.13	54.30	3.24
5	43.26	2.75	46.56	3.19
6	59.14	3.27	65.89	4.30
7	43.78	2.96	49.49	3.29
8	35.34	2.11	38.51	2.57
9	34.89	1.83	40.16	4.21
10	24.40	3.37	25.62	2.24
11	26.14	2.86	27.36	2.14
12	34.78	2.88	36.23	2.67
13	11.36	1.77	13.38	2.28
14	46.31	2.28	51.32	2.50
15	45.46	2.10	51.07	2.24
16	34.06	2.49	37.17	3.46
17	37.03	4.50	36.93	4.20
18	40.90	3.78	43.59	2.53
19	117.48	8.19	120.26	7.55
20	18.36	2.44	20.95	2.77
21	30.39	3.11	35.51	3.58
22	20.82	3.18	24.17	2.83
23	30.14	3.56	31.35	7.66
24	35.42	2.77	40.50	5.03

TABLE IX

MEAN AND STANDARD DEVIATION VALUES FOR FEMALES IN THE NORMATIVE SAMPLE

	Age 10		Age 14	
Measure	Mean	S.D.	Mean	S.D.
1	35.28	2.18	35.38	3.47
2	48.36	2.65	53.38	4.32
3	55.14	3.32	60.64	2.75
4	48.56	2.93	55.30	3.33
5	42.35	3.63	43.98	3.85
6	59.02	3.60	66.00	4.54
7	43.28	2.65	48.73	3.08
8	34.03	2.53	38.12	2.33
9	33.16	2.94	39.39	3.57
10	24.04	2.93	25.99	3.25
11	24.35	2.20	26.52	2.09
12	35.10	2.44	36.51	1.76
13	10.97	1.86	13.21	2.91
14	44.67	1.44	48.70	2.20
15	43.83	2.16	48.51	2.26
16	34.38	3.52	35.57	3.72
17	34.35	4.45	35.64	5.32
18	41.50	2.77	46.66	4.61
19	122.40	9.82	114.38	9.42
20	19.48	2.83	20.96	2.76
21	32.94	4.36	33.25	4.50
22	19.09	2.58	21.28	3.90
23	21.91	5.59	22.14	3.58
24	35.31	3.06	40.68	2.78

TABLE X

COEFFICIENTS OF CORRELATION

(ERROR STUDY)

Measure	Correlation Coefficient
1	0.5688
2	0.8841
3	0.9882
4	0.9601
5	0.8190
6	0.9235
7	0.9541
8	0.9532
9	0.9243
10	0.8684
11	0.8458
12	0.8194
13	0.7079
14	0.9499
15	0.8908
16	0.9365
17	0.8019
18	0.8880
19	0.7871
20	0.4536
21	0.7112
22	0.7420
23	0.5632
24	0.9487

FIGURE 13

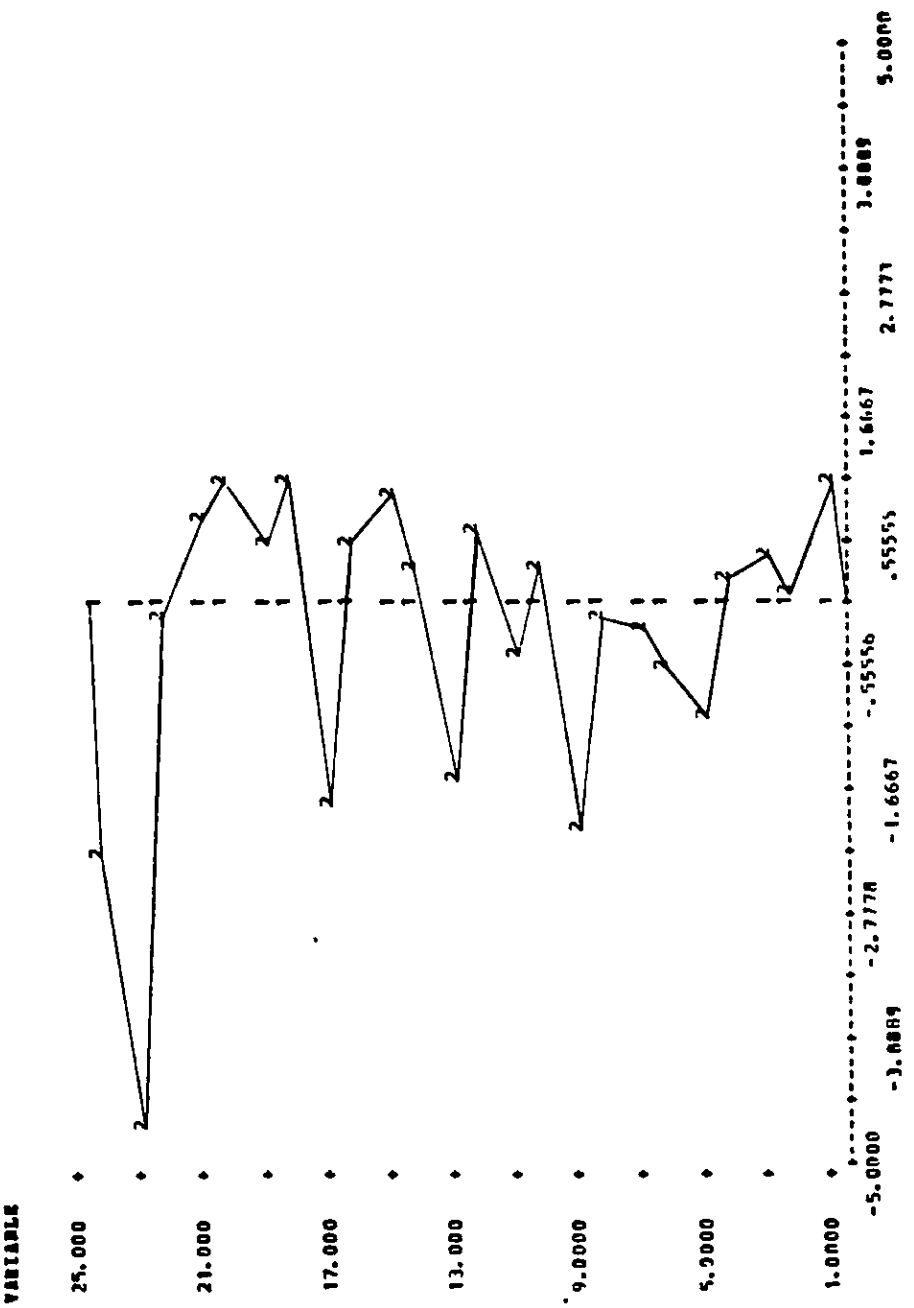
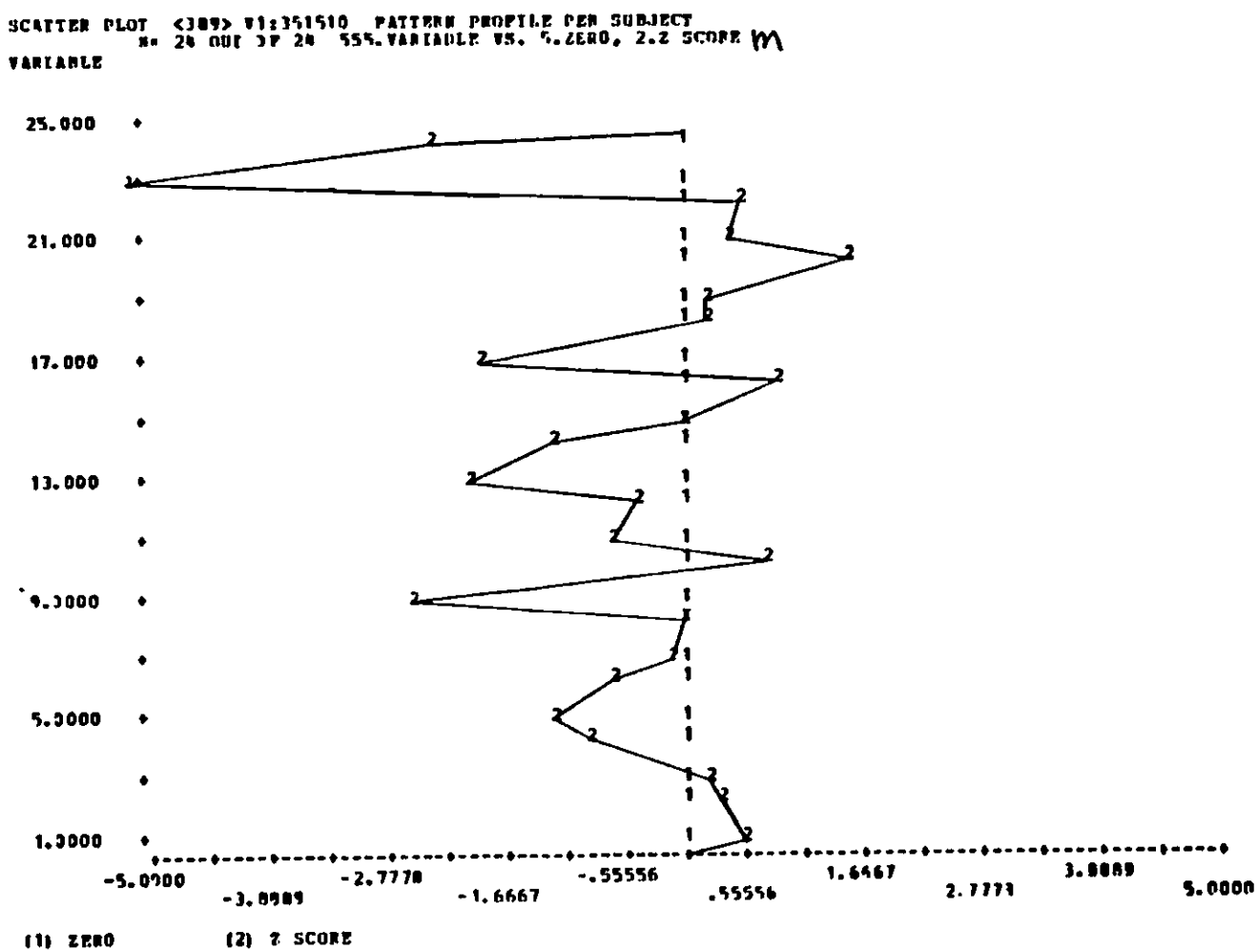

SCATTER PLOT <178> V1:230010 PATTERN PROFILE PER SUBJECT
N= 24 OUT OF 24 55%,VARIABLE VS. 5.2880, 2.2 SCORE W
VARIABLE
25.000
21.000
17.000
13.000
9.0000
5.0000
1.0000
-5.0000
-3.8889
-2.7778
-1.6667
-.55556
.55556
1.6667
2.7777
3.8889
5.0000
(1) ZERO
(2) Z SCORE

FIGURE 14


SCATTER PLOT <389> V1:351510 PATTERN PROFILE PER SUBJECT
N= 24 OUT OF 24 555.VARIABLE VS. %.ZERO, 2.2 SCORE
VARIABLE
25.000
21.000
17.000
13.000
9.0000
5.0000
1.0000
-5.0000
-3.8889
-2.7778
-1.6667
-.55556
.55556
1.6667
2.7771
3.8889
5.0000
(1) ZERO
(2) Z SCORE

different genetic backgrounds, their pattern profiles are quite similar. Thus, they could be expected to exhibit similar osseous configurations for some morphologic relationships.

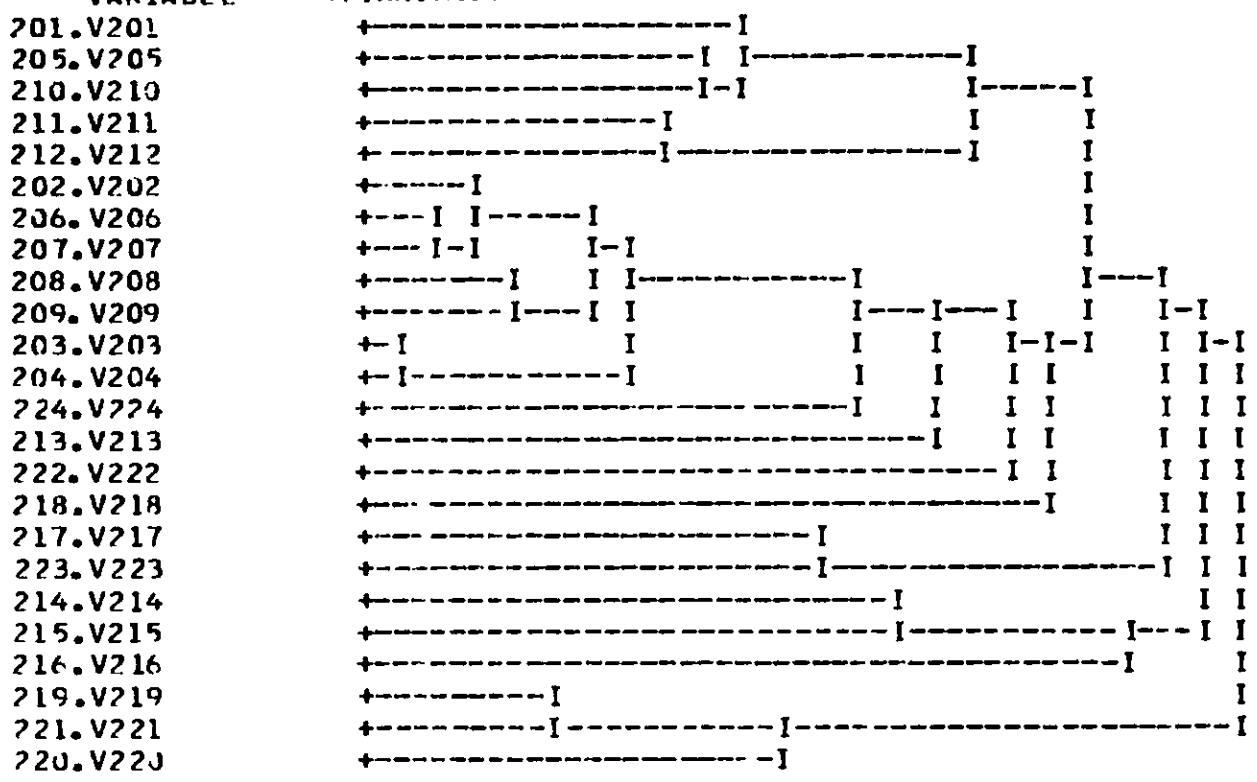
Cluster Analysis

Subjecting the cases to computerized cluster analysis resulted in 17 sets of clusters. Figure 15 illustrates the results of clustering the cases by variable. The computer took all 400 cases in the sample and clustered the variables according to the degree of similarity between them. The results of this set give a relative idea of the "power" of the individual measures in terms of their ability to cluster the cases distinctly (i.e., which measures are the most "informative"). The distances recorded at the bottom of Figure 15 (and all subsequent cluster sets) are given as 1 minus the product moment correlation coefficient (1-r). For purposes of this study, an r value of 0.6 has been selected as the minimum measure of distance in determining the discreteness of the clusters. The distance r is a measure of similarity and ranges from +1 (total similarity) to -1 (total dissimilarity).

Clustering the sample by age and sex yielded 4 sets of clusters (10 year old males, 10 year old females, 14 year old males, 14 year old females). As can be seen in Figure 16, the results of clustering the 10 year old males resulted in 11 groups

Figure 15. Cluster analysis by variable.

```
CLUSTER ANALYSIS  CASES=STANDARD:MISS
BYVARIABLE N=401 ALGORITHM=AVERAGE DISTANCE=CORRELATION
```




```
D   . . . . . . . . . . . . . . . . . . . . 1
I   1 1 2 2 3 3 3 3 4 5 5 5 6 6 6 7 7 7 8 8 9 9 .
S   3 5 1 5 1 4 6 8 3 5 5 9 0 4 7 2 4 7 2 3 1 3 0
T   2 3 3 9 2 3 8 8 5 2 3 2 8 5 2 3 5 0 2 5 1 1 1
A   7 9 2 6 4 9 1 7 2 5 4 4 5 6 2 3 0 4 7 2 9 2 1
N   9 6 9 9 8 9 9 5 2 8 1 7 3 4 4 9 4 7 4 3 8 5 4
C
E
S
```

of cases at a distance level of 0.4 (r = 0.6). Random members would result in approximately 60 clusters at this level. The fact that 11 cluster appeared implies that there is an anatomic basis for the existence of discrete clusters or morphologic subgroups. The results of the 10 year old female and both 14 year old cluster sets all showed at least 50 groups at the distance of 0.4 (r = 0.6). Subjecting the data to the same clustering program, with measures 1, 20 and 23 deleted, due to their low correlation coefficients (Table X), resulted in almost identical clusters. Therefore, deleting those particular measures having low correlation coefficients did not seem to affect the data.

In an attempt to determine if the same individuals clustered together at different ages, 10 and 14 year old males were evaluated as a single group, as were the 10 and 14 year old females. The results of this attempt were not productive at the r = 0.6 level. A given individual in this group did not tend to cluster with him/herself any more strongly than with individuals in other groups; indeed, it was surprising that the tendency was for individuals at age 10 to cluster with those individuals at age 14 less strongly than with individuals belonging to other groups. This points out both the extreme nature of variation in morphologic relationships and the changes that take place in proportionality of anatomic regions at ages around the growth spurt.

Figure 16. Cluster set of 10 year old males in the sample population.

Figure 17 illustrates the results of analyzing all 10 year old individuals as a single group in an attempt to determine if these cases cluster together by sex. A dot after the case number denotes a female individual. It should be noted, in Figure 17, that all females cluster together at the top of the figure, whereas all males, with one exception, cluster together at the bottom. The cases indicated by an asterisk were entered into the sample in error and are not 10 year old sample cases.

Figure 18 shows the results of analyzing all 14 year old individuals together, as above. Again, a dot behind the case number denotes a female case. Here we see, overall, less distinct groupings than for the 10 year old group. The cases tend to group with like sex, but differentiation by sex is considerably reduced (compare Figure 18 with Figure 17).

Attempts to cluster the cases by differences in muscle pattern were carried out for 14 year old females using measures for the masseter, medial pterygoid, lateral pterygoid and temporalis muscles. This was done to determine if one muscle was more effective than another for purposes of grouping the cases. All of the muscles tended to demonstrate the ability to cluster cases distinctly at $r = 0.6$. The temporalis measures, however, appeared to be less reliable in this regard than the other muscles.

Figure 17. Cluster set of 10 year old males and females.

. indicates female cases
* indicates cases admitted to the sample in error.

CLUSTER ANALYSIS <2> USING AVERAGE VARIANCE CASES=STANDARDIZE
CASEWISE MISSING ALGORITHM=AVERAGE DISTANCE=CORRELATION

USING: 201.V201, 202.V202, 203.V203, 204.V204, 205.V205, 206.V206, 207.V207, 208.V208, 209.V209, 210.V210, 211.V211, 212.V212,
213.V213, 214.V214, 215.V215, 216.V216, 217.V217, 218.V218, 219.V219, 220.V220, 221.V221, 222.V222, 223.V223, 224.V224

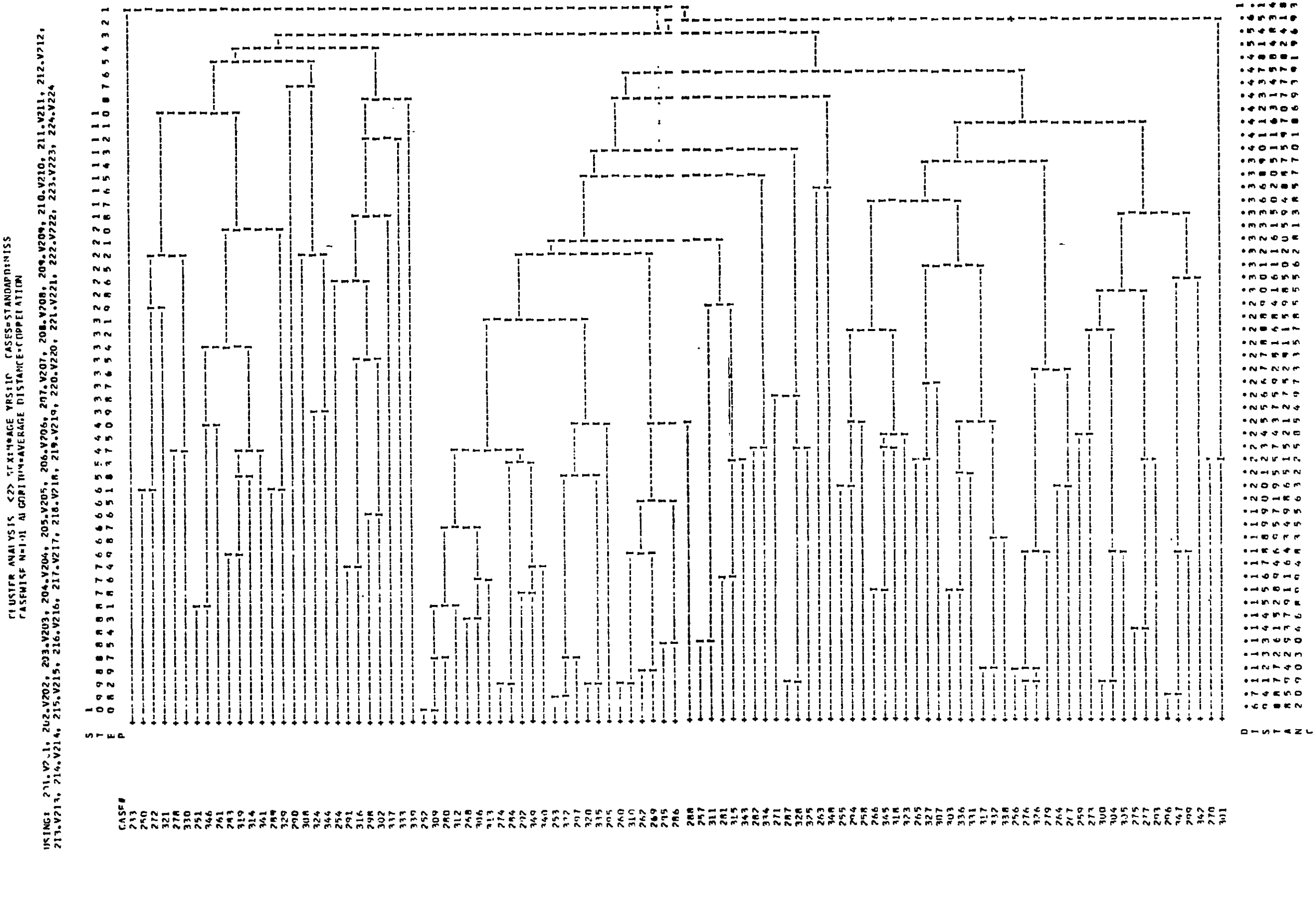


Figure 18. Cluster set of 14 year old males and females.

. indicates female cases.

DISCUSSION

It was the intent of this study to evaluate some of the skeletal relationships of the face by means of an analysis of certain collateral relationships with various muscles and ligaments. Measurements were made between points selected to represent origins and insertions of these muscles as visualized in lateral cephalograms. The cases utilized were males at ages 10 and 14 years, and females at the same ages. The same individuals were used at both ages. The cases were subjected to cluster analysis as previously explained.

This procedure resulted in apparent clustering of 10 year old males into distinct groups (Figure 16). The cephalograms of the cases within the 11 clusters, and each cluster's characteristics were studied in a preliminary attempt to recognize any general morphologic features that might characterize a particular cluster. These features included conventional Angle classification, long face-short face, and open-deep bite. In addition, measures for gonial angle, ANB angle and facial height (Me-ANS) were taken. In viewing the clusters, however (particularly those groups having large numbers of individuals), common morphologic or cephalometric characteristics were difficult to recognize with consistency. It was quite apparent that characteristics which might be used to

describe one particular group were essentially inappropriate for other groups. While one or two measures or morphologic features might be important in describing one group, with other features not relevant, in another group the reverse could hold. It was readily apparent, also, that attempting to apply conventional cephalometric measures to distinguish within and among groups was in fact an error in reasoning. This is because many conventional cephalometric measures have no common basis with respect to the biologic rationale used to segregate the clusters identified in the present study. Also, standard measures are incapable of distinguishing morphological subgroups, and it was in fact inappropriate to consider that the problem could be part of the solution. Further, if conventional cephalometrics were effective morphologic discriminators, they would have been used for such purposes successfully in the past and no need for this type of study would exist.

In viewing the cephalograms, especially those consisting of a smaller number of cases, it was readily apparent that certain subjective similarities exist in some of the clusters. However, it was extremely difficult to precisely identify the nature of these similarities. Part of the problem lies in the fact that it is presently not known just what descriptive parameters to use, or what actual anatomic features to look for. It is also probable that some of the measures used in clustering the cases actually hinder the process by adding "noise". What is necessary, before

an adequate description can be made, is further exploration of the data taking into consideration other biological parameters, other ages, a larger sample, and the development of an external verification method having an appropriate biologic basis.

While it would have been potentially beneficial to be able to describe the anatomic features for 10 year old male clusters, no readily apparent characteristics were evident. This does not necessarily preclude the existence within clusters of discrete morphological, developmental or functional characteristics, even though presently unrecognizable.

The above limitations in evaluating the possible meaning of the clusters identified in this study not withstanding, the clearly recognizable distinction of the two general clusters according to sex (at 10 years of age) is significant. As Figure 17 illustrates, sexual dimorphism can be demonstrated with almost 100% accuracy. This demonstrates that a fundamental and discrete difference exists between male and female muscle relationships at this age. The one male case that clustered with the females had muscle characteristics of the opposite sex at least according to the criteria presently used. At age 14 the ability to demonstrate sexual dimorphism, however, was reduced (Figure 19). This is most likely due to increased variability of skeletal relationships at the age of 14 years. The pubertal growth spurt may also be related to this variability. Since males generally lag behind females by

about 2 years in some features of growth and development, and tend to mature over a longer period of time, a greater spread of anatomic variations can be expected between the 10 year old and 14 year old females as well as between the 10 to 14 year old males. If a sequel to this study should be undertaken, the best ages (younger and older) to evaluate are those in which the body is less involved in active growth changes dealing with sex-divergent development. It is felt that the positive results obtained, at least in the pre-pubertal male population, were due to the fact that a biologic rationale provided a basis for the selection of landmarks and measures as opposed to justifying landmarks and measures on the basis of reliability, expediency, convenience or tradition. The fact that these same criteria do not seem to apply at post-pubertal ages suggest that these morphological relations are masked by other anatomic variables introduced during the pubertal growth spurt.

It is expected, in a methodology such as this, that all measures are not of equal value in their ability to render useful information. In fact, in terms of clustering, some of the variables may confuse the results. In an attempt to determine which measures are the best descriminators, a cluster analysis by variable was performed, the results of which are shown in Figure 15. Using the distance 1-r = 0.4 to separate measures, it can be seen that 11 of the measures had r values above this distance. Table XI is a list

of all the measures ordered according to their discriminative ability. This gives information as to which measures are the most useful and which may, in fact, be misleading in terms of clustering attempts. The measures that are most informative, in terms of clustering, appear to be associated with the masseter and medial pterygoid muscles (Table XI).

The implications of this study appear to be two-fold. First, the approach used appears to be a start in terms of deriving subgroups, perhaps including those associated with different types of malocclusion, within the population as evidenced by the discrete clustering of the 10 year old males. This could ultimately be applicable for the refining of prediction schemes and individualizing treatment plans. Second, it appears to demonstrate the ability to classify individuals by sex according to their muscle relationships. If this study were to be repeated using different samples or further investigations done using this methodology, it would be prudent to select variables that have been shown to be the most powerful discriminators while eliminating those of questionable value as shown in Table XI. In terms of population age groups, it appears that the selection of ages farther removed from the pubertal growth spurt may be a more effective choice, thereby reducing the extremes of variability among the relationships of the sample population. This might also serve to elaborate the present findings of dimorphism. A more

TABLE XI

LIST OF MEASURES RANKED ACCORDING TO DISCRIMINATIVE POWER

	Measure	r value
Most Informative	3 (masseter)	0.87
	4 (masseter)	0.87
	6 (medial pterygoid)	0.85
	7 (medial pterygoid	0.85
	2 (masseter)	0.79
	8 (medial pterygoid)	0.75
	9 (medial pterygoid)	0.75
	19 (temporalis)	0.69
	21 (temporalis)	0.69
	11 (lateral pterygoid)	0.61
	12 (lateral pterygoid)	0.61
Least Informative	5 (medial pterygoid)	0.56
	10 (lateral pterygoid)	0.56
	1 (masseter)	0.45
	20 (temporalis)	0.45
	17 (temporalis)	0.41
	23 (stylomandibular)	0.41
	24 (stylomandibular)	0.39
	14 (buccinator)	0.35
	15 (buccinator)	0.35
	13 (buccinator)	0.33
	22 (sphenomandibular)	0.25
	18 (temporalis)	0.23
	16 (buccinator)	0.16

complete sample population should include some untreated Class II, Class III and open bite cases.

As explained earlier, this study resulted in 11 discrete groups of 10 year old males. In the Angle classification system, which is still in use today, there is recognition of only three basic groups. Many workers in the field of clinical orthodontics and craniofacial research have recognized the existence of many more types of faces, but attempts to classify and describe them using conventional cephalometric standards have not been successful. The most significant finding of the present study is the demonstrable existence of sexual dimorphism at one pre-pubertal age (10 years) as an important characteristic of clustering according to muscle pattern. Previous work has not demonstrated this. Within the two male and female clusters there also appears to be other underlying morphological subgroups as well, although much less clearly recognizable. At the age of 14 years the overriding sexual clustering appears to disappear and the morphological characteristics of the cases takes presidence. Dimorphism remains however, but not expressed to such a degree as at age 10. Therefore, sexual dimorphism is a distinct early entity but appears to lose its "power" at later ages insofar as the muscle patterns previously stated are concerned. This may explain the difficulty in characterizing sexual dimorphism which is usually topigraphically apparent at later ages, but which is difficult to demonstrate statistically using most standard cephalometric measures.

SUMMARY AND CONCLUSIONS

Throughout its evolutionary process, cephalometrics has carried with it the anatomical landmarks and measures utilized, for the most part, in physical anthropology. Because of this, cephalometric analysis still relates the relationships of skeletal components on a purely static basis rather than a dynamic one. Since the relationships between function and growth are well documented in the literature, it seems obvious that the next evolutionary step in cephalometric analysis should attempt to relate the skeletal components of the face on a much more biological basis. This study was an attempt to do so.

Cephalometric points were selected to represent the origins and insertions of various muscles and ligaments that attach to and influence the growth and displacement of some of the principal skeletal components of the craniofacial complex. Measurements were made between points to establish muscle patterns for 400 sample subjects. The sample was divided into 10 year old males, 10 year old females, 14 year old males and 14 year old females. This was done to attempt to classify and define possible subgroups that may exist in these populations.

The sample was subjected to various cluster analyses using the computer facilities of the Center for Human Growth and Develop-

ment at the University of Michigan and resulted in the generation of 11 subgroups within the population of 10 year old males. A subjective evaluation was attempted as to the morphologic picture presented by the cases in each of these subgroups. The clusters were indistinct in the female population as well as the 14 year old male population, probably due to the extreme nature of variation in relationships within these populations associated with the pubertal growth spurt.

It was unexpected to find that the entire 10 year old population (males and females), when subjected to clustering, demonstrated almost totally separate groupings according to sex.

Further studies are now indicated to refine the method and to evaluate the morphologic nature of these relationships at different ages.

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