BONE GROWTH ALTERATIONS AFTER UNILATERAL MASSETERECTOMY OR MOLAR EXTRACTIONS: A QUANTITATIVE MICROSCOPIC ASSESSMENT

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There is a great deal of difference between the eager man who wants to read a book and the tired man who wants a book to read.

G. K. Chesterton 1874-1936

ABSTRACT

The fundamental biological principles that operate during the development of bone and muscle have provided the substance for continuing controversy, in many fields, under the "form and function" title. Natural anomalies and experimentally produced aberrations (due to altered functional states) have demonstrated the existence of a relationship between the shape of the hard tissue record and the activities of the enveloping soft tissue elements. It is to be expected that knowledge of the "natural" occurrences will be provided by study of the unusual.

The gross alterations that might be expected after unilateral masseterectomy or molar extraction in the rat have been documented; and suggestions made as to how these findings came to be. The basis for popular opinions, regarding mechanisms and cause and effect relationships, is largely predicated on theoretical assumptions of the effects of variables such as pressure and tension, nutrition (blood supply), internal architecture and age. More sophisticated experiments are continuing to corroborate or refute these hypotheses concerning bone growth rate, quality, growth direction and configuration. The present study was undertaken to quantify bone growth rate and bone configuration alterations subsequent to functional alteration at a microscopic level. Specific anatomical locations were assessed after two types of functional disturbance had been

produced: unilateral masseter muscle extirpation and unilateral maxillary molar extraction.

The subjects were male Long Evans strain rats which were studied longitudinally over a 74 day experimental period. Three experimental groups comprising 30 animals and consisting of an extraction group, a masseterectomy group, and a sham muscle operation group were examined and their bone growth measurements for selected sites (cranium and mandible) were compared with those of a matched control group. A standardized technique involving a sequence of five vital stain injections, which produced fluorescent bone markings, was used to microscopically assess bone growth increments. A total of 30 sites in six cross sections of the mandible, and 58 sites in seven coronal sections of the cranium were investigated.

Statistical evaluation of growth differences between seven sub-groupings was achieved using the Duncan multiple range test for each growth interval studied. The usual statistics for mean differences had been compiled. Graphical representation of growth rate curves allowed visualization of important alterations.

Numerous significant findings, often at odds with widely accepted postulates, were derived from the mass of quantified data. Some of the deductions that were suggested as a consequence of this study follow:

1. Each type of functional alteration was associated with a characteristic bone growth curve configuration that was

typical for the majority of growth sites. A generalized control mechanism that is linked with experimental age might be proposed.

2. The development of asymmetry was due to translation of bones rather than differential growth, and was mediated by sutural adjustments. There was a tendency to re-establish or maintain symmetry with remodelling activity.

3. Masseter removal produced an <u>increase</u> in bone apposition at the operated muscle attachments (masseteric ridge) and a change in growth direction to yield a gradual obliteration of the attachment prominence. The concepts of a "release response" and efficiency in the mode of shape alteration are supported. The validity of the conventional tension hypothesis is questioned.

4. Sites of muscle attachment for unaltered muscles (temporalis and digastric) did not display a growth stimulation due to a possible greater functional demand.

5. Tooth extraction resulted in localized growth reduction but increased apposition in the neighbouring alveolar process, presumably to re-establish structural strength.

6. The dentine apposition curves displayed an individual pattern markedly different from bone apposition curves.

7. A retardation of maturation occurred as a result of functional intervention. Trabecular patterns failed to mature in the operated masseterectomy hemimandibles. The growth dominance reversal of the ectocranial and endocranial

surfaces was retarded as was that of pre- and postantegonial notch sites. An immature degree of lower incisor curvature was retained in some experimental groups. Such maturational lapses were more pronounced on the operated side.

8. The rat mandible develops differently from the human mandible because of the influence of the continually erupting incisor. Both anterior and posterior directions of area relocation processes were revealed.

9. Variables other than the physical absence of the muscle play an important role in establishing resultant aberrations. Circulatory alterations typify such variables.

10. A longitudinal design utilizing sequential vital staining and fluorescent microscopy is an effective method of assessing the amount and direction of bone growth. Such information is a prerequisite for formulating hypotheses regarding alteration mechanisms.

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* Means and Standard Deviations of the Standardized Coordinates in Millimeters applies to all appendices.

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INTRODUCTION

The students of bone growth are numbered throughout many disciplines - anthropology, archeology, anatomy, paleontology, orthopedics and orthodontics to name a few. Their common interest in the development of skeletal structures stems from the fact that the bones and teeth provide a permanent record of the growth events that determined their ultimate morphology and consistency. To comprehend the importance of these final manifestations a knowledge of the mechanisms of bone growth and bone growth alterations is required. Knowledge of these processes is still limited to superficial generalizations. The sophisticated details of the regulatory mechanisms are not yet defined.

Experimental alteration of normal function provides a means of elucidating the normal by studying the abnormal. There have been too few such investigations in recent years which could now use the improved techniques available for a refined assessment of growth occurrences. Let us not hastily dismiss surgical intervention procedures as being "mutilation" and "unphysiologic". No experiments of any sort, other than those produced by the whims of Nature can claim to be physiological. Indeed the designation of techniques involving altered nervous conduction or chemical agents as "more physiological" is a moot point. More relevant is cognizance of the factors which may be contributing to the development of the observed results.

The orthodontist's interest in craniofacial growth and development arises from a desire to manipulate the variables affecting bone morphology to achieve a desired result. The determination of the role that functional stresses play in development of skeletal characteristics would provide the basis for diagnosis of functional problems and determination of associated therapy.

An experimental design involving the longitudinal study of rats subjected to two forms of functional alteration: unilateral masseterectomy, and unilateral maxillary molar extractions; was proposed to achieve a number of objectives:

(1) Description of the morphological alterations (in the coronal plane) resulting from a change in function, by means of the parameters of bone growth rate and direction.

(2) Assessment of the relative contribution of transformation and translation in achieving the altered growth pattern.

(3) Examination of the validity of gross skeletal findings in the light of bone growth at specific sites determined by the more sophisticated microscopic method.

(4) Development of general hypotheses regarding the mechanisms of bone growth alterations.

LITERATURE REVIEW

The role of functional stress in the growth and development of osseous structures has been a topic of continuous research for over a century. The initial impetus for examination of experimental models of altered function was generated during the second half of the nineteenth century. The philosophical thoughts of that day were concerned with questions related to the origin of man, his evolution, and the influence of genetics and environment in his ontogenetic and phylogenetic development. The work of Darwin concerning evolution, and the rediscovery of Mendel's "Laws of Heredity" played a role in firing the curiosity of the scientists of that era.

Investigators representing many varied disciplines focused attention on a common point of interest. How did organisms grow and develop; and what were the mechanisms which regulated these processes and achieved the infinite variations that could be observed? The same problem is still under investigation today. The attack on these problems was mounted on a wide scale limited only by the research techniques and equipment then available and the imagination of the investigator. One field of endeavor that looked particularly promising was the study of bone and teeth since these calcified tissues are the only tissues leaving a semi-permanent record of their development. A most useful tool for the delineation of such a record was rediscovered by Belchier (1736) who noted the red staining of bone that resulted from the feeding of madder. Duhamel (1742) then applied this finding and recorded the appositional growth in thickness of long bones and proposed the theory of interstitial growth which has since been shown to be erroneous. Vital staining techniques using multiple bone markings became a common investigative method. Considerations of the effects of various staining agents on normal growth and the mechanisms of stain binding have been reviewed elsewhere (Cleall, 1964; Jacobson, 1969). The technique of vital staining has been refined to the multiple marking method used in the present study to determine the direction as well as amount of bone growth. Information regarding the pattern of resorption can also be derived.

The radiographic examination of bone trabeculae (internal structure) under various conditions of stress resulted in Wolff's Law of Bone Transformation (1892) which was given a mathematical model by Koch (1917). The observation that functional demands in some way affected the morphology of bone was first investigated as early as 1857 by Fick using the technique of experimental intervention. He was not alone in this pursuit as numerous other investigators in other countries adopted a similar approach (Anthony, 1903, 1909; Gudden, 1877; Bidder, 1873; Neubauer, 1925).

The basis for experimental intervention studies was the idea that came from medical teaching. To understand the normal, it is often easiest to study "abnormal" situations. These may be experiments of nature due to her tendency for variation or man-induced abnormalities. Many different types of intervention have been utilized in studying craniofacial alterations. Nerve resection, alterations in hormonal balance, ostectomy of various parts, tooth extraction, muscle and suture extirpation, muscle sectioning, and the application of mechanical devices to change stress patterns are a few examples.

Normal Growth. The macaca rhesus monkey and various strains of the Norwegian rat are experimental animals commonly used in growth studies of the craniofacial region. The rat is particularly suitable since it is easily handled, relatively inexpensive to keep, and the cranium is of a size suitable for hard tissue sectioning and microscopic analysis. The normal growth patterns of the skull and mandible were found to have common features among species of mammals.

Hunter (1771) is often quoted as having made the most significant early contribution to the understanding of mandibular growth. He used madder fed pigs to discover that (1) the mandible increases in length by apposition at the posterior border of the ramus, (2) remodelling occurs by resorption of the anterior border of the ramus, (3) the condylar and coronoid processes increase in size above the line of the teeth, and (4) the shedding of teeth is always accompanied by resorption of alveolar bone whereas eruption of teeth is accompanied by growth of alveolar bone. These findings are still generally accepted today.

The pig was also studied by Brash (1924) in his investigation of cranial vault growth. His observations of the surface phenomena resulting from vital staining on a longitudinal basis led him to believe a simple mechanism of ectocranial deposition and internal resorption. Staining in the sutural areas was said to be the result of secondary reformation to maintain the relative position of the suture during increase in cranial size, and not of separating growth. Brash regarded the growth of the cranial base as analogous to that of long bones.

During the gradual progression from the subjective evaluation of stain intensity observed from the surface of the gross specimen to measurement of specific growth sites in sectioned material, there has been considerable disparity in the findings reported by various investigators. As knowledge in the field of vital staining was amassed, it was discovered that many of these apparent disparities were reconcilable on the basis of a lack of understanding of the vital staining mechanism.

The variables of animal age (rate of growth), dosage and concentration of stain, timing of the injection sequence, superimposition of equally stained surfaces (in sutures), growth direction, and the masking effect of new bone over old are all important considerations in the determination of the final subjective impression.

Minutes after the intraperitoneal injection of a vital stain (Cleall, 1964) all bone surfaces and other collagen structures demonstrate the stain color. As the agent is cleared from the circulation, the weakly bonded stain can be removed from areas undergoing resorption or no bone growth. In areas undergoing apposition, however, the stain line is incorporated into the newly formed bone by succeeding layers. The gross appearance of an area of growing bone is dependent upon the interval between stain injection and examination as well as the rate of growth and previously indicated factors. Bone deposited after the stain has cleared the circulation is unstained (white) and serves to gradually decrease the intensity of stain color noted on surface appraisal. The reverse process would occur should resorption now begin in the area. The dosage and time related factors also serve to modify the stain intensity and location and the end result is a misinterpretation of the meaning of the surface stain pattern.

The indirect method of vital staining (madder feeding), used by the early investigators, is a form of continuous vital staining and requires separate interpretive understanding. The length of the feeding period and the interval between the end of madder feeding (if any exists) and sacrifice of the animal are important considerations. The quality of the stain might also differ from that produced by the established doses now in use.

These considerations may explain why Massler and Schour's (1951) study of cranial bone staining did not support Brash's conclusions.

Massler and Schour utilized a single injection of alizarine red S into animals of different ages (cross sectional technique) and noted a staining difference with age.

> 1. A period of generalized bony growth from birth to about 60 days of age, which was characterized by the active deposition of bone upon all bony surfaces. The rate of growth at different sites did vary, however. This period is characterized by very rapid increase in size of the cranial vault with only minor changes in proportions. The latter are due to differences in the rate of growth at the different sites.
>
> 2. A period of localized growth after 70 days of age characterized by the fact that bone deposition occurs only at certain sites. These sites were, in general, the same that showed the most rapid rate of growth during the previous period. Since growth is confined to localized areas, the predominant characteristic of this period is a marked change in the proportions of the cranial vault with only a relatively slight increase in size.

Additional conclusions credited the sutures as being the most important growth sites with the increase in length being greater than that in breadth. Sutural serrations were seen as a gross manifestation of trabecular growth due to fiber tension. Deposition of bone was noted on endo- as well as ectocranial surfaces to allow an increase in thickness of the cranial vault bone. Increases in width were noted to be completed by the 20th day.

In consideration of the size of the structures being measured, the use of calipers reading in 10ths of a millimeter seems relatively crude. The ability to accurately ascertain the original sutural edge by later observation of stain intensity reflected through newly deposited bone is questioned. A tendency for inflation of recorded amounts of growth is a possible result (2.5 mm. of total width increase in 10 days?). This type of study lends itself more properly to the longitudinal rather than cross-sectional design and the use of the direct method of sequential vital staining assessed by microscopic measurement after sectioning of the specimen.

Moore (1949) partially followed such a design in his study of only a single monkey that had been injected with alizarin red S on two occasions. He used the technique of surface cutting and photography to overcome the technical difficulties of serially sectioning an object as large as a monkey skull. He verified the importance of sutural growth and the presence of dye on all skull surfaces as well as on the internal structure of the cranial base.

To further clarify the proportional changes observed as the short nosed, round headed, new born rat undergoes flattening and elongation of the head, and a marked growth of the snout, Baer (1954) assessed the influence of differential size increase of individual bones on the form of the skull. He disagreed with Weinmann and Sicher's (1947) statement that the cranial vault bones flatten out during growth as a result of apposition on the endocranial surface in the central areas of the bones and resorption of the endocranial surface near the sutural margins. Baer's interpretation of the surface stain phenomena, "The surfaces of the vault show the greatest concentration of stain near the sutural margins and less intense staining in the central area," is subject to previously noted criticisms. Absolute growth curves supported Massler and Schour's observations of very rapid growth in the younger animals (before the age of twenty days). As a result of the differential growth of the individual bones, the cranial form was found to be modified concurrently with changes in proportion. Baer stated the importance of sutural growth but also found appositional growth of the vault bones evident. Unequal growth of adjoining bones at a sutural site, a common tension line, suggested that intracranial pressure was not the only factor controlling sutural growth.

The changes in cranial form, by translation of bones relative to each other, were examined by Baer. A hypothesis of spatial reorientation to yield cranial vault flattening ("hinging" at the sutures) was proposed.

It is likely that a combination of the factors supported by various investigators represents the true occurrence in cranial vault growth. The differences between authors are therefore not absolute but a matter of emphasis.

Moss (1954, 1960) has popularized a concept of "functional matrices" which explains cranial vault growth by distinguishing between transformation and translation changes mediated by soft tissue components. He stated that sutures do not provide a primary separatory force, as do epiphyses, but are secondary adjustment sites only.

Such a viewpoint was supported by Scott (1954) who hypothesized that the growth centers lie in the chondrocranium. The impetus for translation of bones is provided by cartilaginous growth while the sutures respond passively and are not growth centers.

The place of the mandibular condyle in the hierarchy of "growth centers" was investigated by Koski and Ronning (1969) who attempted to demonstrate independent growth of the mandibular condyle in tissue culture. Their findings suggested that the condyle was not a primary growth center analogous to an epiphysis, but that the condyle did show more independent activity than a fibrous suture.

A normal occurrence of consequence to muscle resection studies was discussed by Hoyte and Enlow (1966).

> During the growth of a bone, outer (periosteal) surfaces in many areas undergo normal remodeling processes involving resorptive removal. Attachments of muscles commonly occur on such outer resorptive surfaces. The cortex in these regions grows in an inward direction by bone deposition on endosteal surfaces. In some areas of a bone, a portion of a muscle can be inserted onto a depository surface, but other parts of the same muscle may be attached onto an adjacent resorptive surface. It has been generally assumed that the pull of a muscle acts to directly stimulate deposition of new bone, and that attachments of muscle are thereby responsible for determining the gross morphology of a whole bone. In view of the foregoing considerations, a re-evaluation and an expansion of this concept is now needed. Muscle pull, in many regions of a bone, can be associated with normal cortical recession (involving surface resorption) as well as with outward bone deposition.

The circulatory system carries the necessary building blocks for bone growth. It has been demonstrated by Sunden (1967) that skeletal blood flow is inhibited by muscular contraction. The purely mechanical interference with the extraosseous vascular bed seems to be of importance to the intraosseous flow. It was also possible to observe an increase of intraosseous flow that coincided with an accelerated growth after longitudinal growth stimulation by peripheral nerve sectioning. A certain time lag between the curves of flow and growth suggests that the increased flow is the primary factor.

Huelke and Castelli (1965) studied the blood supply of the rat mandible. Their findings indicated that the coronoid, condylar and angular processes of the mandible are supplied by vessels which are primarily concerned with the nutrition of the muscles that attach to these areas and not from the inferior alveolar artery. Sunden's work becomes more important once this relationship of bone, blood and muscle is recognized.

Muscle Surgery. The inverted pyramid, building block style of development of scientific concepts was well illustrated by the successive investigations concerning the surgical alteration of muscle function. Each study appraised the evidence current at the time before adding more blocks of evidence or a new viewpoint as the hypotheses surrounding form and function phenomena were defined.

Although earlier experimental alterations of functional influence had been reported (such as sectioning of the temporalis in dogs by Anthony (1903) and Anthony and Pietkiewicz (1909)), the first significant report was presented by Pratt (1943). His experimental procedure involved the unilateral blunt dissection of the masseter muscle except for the portions arising from the medial portion of the zygomatic arch and the infraorbital foramen. Differences in observed deformities were linked with the amount of masseter muscle removed. Ligation of the external jugular vein and interruption of the zygomatic arch in some specimens were also carried out. No deficiency attributable to injury or sectioning of the facial nerve was observed.

Of the four rats whose deformities were reported, two died prematurely. This would suggest that the effects of the surgical intervention may have been studied in extreme situations. Pratt was impressed with the ability of the animals to obtain normal nourishment. The deviation of the mandible to the operated side with the resultant malocclusion of incisors was ascribed to unopposed pull of the left masseter. Comparison of left and right hemi-mandibles revealed that the operated side was shorter in the long axis but increased in vertical height. The latter measurement was taken from the occlusal surfaces of the molar teeth and was probably due to differences in molar eruption due to the molar malocclusion. The vertical depth of the neck of the condyle was reduced almost 19 per cent on the operated side. The distance between angular and coronoid processess was also reduced by nearly 9 per cent. No normal animals were used as a control to determine if the unoperated side had been altered.

The masseteric ridge was greatly reduced on the operated side and damage to the periosteum at the time of operation was thought to be the cause of an uneven surface.

It was found that the angle of the mandibular symphysis had deviated to the operated side. The rostrum of the skull had deviated to the unoperated side. An asymmetrical attrition of the molar teeth was reported.

The interruption of the zygomatic arch and the very early age (1 day old) of surgical interference were named as factors responsible for the extreme distortions.

The effect of removal of the zygomatic arch was studied further by Washburn (1946). Of the 6 rats which survived after 5 months, 3 showed slight deviations toward the normal side. The side from which the arch had been removed apparently grew more rapidly and it was suggested that the noted deviations were due to a "release" mechanism. The other 3 rats showed no asymmetries. A deviation was present only when nearly the whole arch had been removed. A second experiment in which only 1 to 2 millimeters of zygomatic arch were removed yielded no asymmetries. The photographs displayed in Washburn's article demonstrate the susceptibility to optical illusion, due to the dorsal curvature of the rostal area, of subjective assessment of asymmetry. Such subjectivity may play a role in the disparity of different worker's reports concerning asymmetries.

The surgical procedure involved in removal of all or part of the zygomatic arch also affects other structures. Eisenberg and Brodie (1965) investigated the antagonism of temporal fascia to masseteric contraction. In their abstract they stated:

> Frontal sections through the right and left arches revealed striking differences between them. The operated side measured approximately 25% less mediolaterally and 16% greater superoinferiorly than the unoperated side. Oriented frontal and basal head x-rays at 5 ft target distance revealed the operated

> side to be 4 mm lower and 2 mm closer to the midline. The lead lines showed the extensive internal as well as external remodeling that had taken place. Deposition and resorption areas indicated the drifting of marrow spaces and of the zygomaticotemporal suture in the direction of the unopposed pull of the m. masseter.

They also cited Kruger's (1948) observation that the zygomatic arch when fractured was rarely pulled down by the masseter. Brodie advanced the possibility of the temporal fascia aiding the relatively weak zygomatic arch to resist muscle pull and gave examples of mammals which presented incomplete zygomatic arches in spite of well developed masseter muscles.

The removal of a portion of zygomatic arch would also alter the fascial attachments. The possibility of reattachment to soft tissue or a bridging of the gap in the zygomatic arch exists. Eisenberg and Brodie cited Holme's (1912) description of a patient with congenital absence of the anterior part of both the arch and temporal muscle, yet there was no depression. The temporal and masseteric fascia were both attached to a narrow tendinous band which bridged the gap in the arch. This might explain the observations reported by Washburn (1946).

Other extrinsic factors also play a role in determining the outcome of surgical interventions. The importance of disturbances to the circulation of the mandible due to removal of the major blood supply via the masseter muscle has been mentioned previously. Felts (1957) regarded bone growth as the result of intrinsic factors whose expression was made possible by the presence of extrinsic factors provided by the muscle such as vascularization.

Washburn (1946) investigated the effect of facial paralysis on the growth of the skull of rat and rabbit. He concluded that asymmetries due to atrophy were toward the paralyzed side while those due to muscle imbalance were toward the unoperated side. In the rat, there was little atrophy of the cheek so maxillary and nasal bones deviated to the unoperated side. In the rabbit, atrophy was pronounced causing the rostral portion to bend to the operated side. More posteriorly some deviation to the normal side was also present. Washburn thereby attempted to explain the differences in the reports of asymmetry proferred by various investigators studying different species and age ranges.

The importance of age differences, when results of different investigations are compared, was demonstrated by Schumacher and Dokladal (1968). " A comparative study was made of the delayed effect of resection in newborn rats, 4-5 month-old rabbits and 3-4 month-old sheep. The rats, which were sacrificed 6 months after operation, showed cranial asymmetries after unilateral resection of the masseter and temporal muscles and brachycephaly after bilateral resection. The rabbits and sheep, which were sacrificed 9 months and 17 months after resection, respectively, showed only secondary changes in the maxillo-mandibular apparatus and in none of the animals was there any sign of brachycephaly. These differences are attributed to the varying degrees of maturity of the animals at the time of resection."

Rogers (1958) examined the influence of asymmetry of the muscles of mastication upon the bones of the face using human skulls. Comparisons of the area of muscle attachments and atrophic skeletal changes revealed a correlation of a unilateral reduction in the temporal lines and a coronoid process with unilateral atrophy of the temporalis muscle. This association was also demonstrated for the internal pterygoid and masseter muscles. Changes in the shape of bones were attributed to bone resorption rather than a "bending" mechanism since there was no change in the pattern of the remaining trabecular bone.

There is also the possibility of differential growth rates acting as the mechanism for achieving shape alterations. The age of the subject would be an important factor in determining whether growth rate alteration or resorption mechanisms might be utilized.

Numerous investigators (Avis, 1959; Boyd, 1967; Horowitz and Shapiro, 1951) have studied the "diminuation" of the coronoid process that results from resection of the temporalis muscle. The absence of alterations to the rest of the mandible supports the concept describing the mandible as a composite of relatively independent parts (Washburn, 1951; Symons, 1954), (1) a coronoid region related to the temporalis muscle, (2) a gonial region related to the masseter and internal pterygoid muscles, and (3) the central area of the mandible which is unrelated to muscle stress.

Condylectomy has also been a popular procedure (Castelli et al., 1971; Moss, 1960). Cullen (1955) excised the anterior bellies of the digastric muscles and concluded that noticable differences in contours of control and experimental rats were evident. Simpson (1962) investigated the response of gonion to resection of the right internal pterygoid muscle and concluded the cleaned skulls showed <u>arrested</u> <u>osteogenesis</u> at the right gonial contour and alteration of the pterygoid plates.

All of these form and function studies have a common deficiency. The observation of an alteration in skeletal contour, usually in the direction of a relative diminution, was interpreted as a lack of bone apposition or resorption in the area concerned in growing animals. Such conclusions regarding the actual occurrences of bone growth at a particular site are questionable unless techniques, such as radiographic implant studies, microscopic assessment of cross-sections of bone, or vital staining have been employed.

The fascial attachment of the branches of the facial nerve to the masseter muscle in the rat is such that section of the nerve is to be expected when the muscle is extirpated. However, Horowitz and Shapiro (1955) stated that the parotid gland and facial nerve remained intact after their masseterectomy procedure. Findings in 12 rats were compared to those in an equal number of control animals; a necessary comparison that is noticably lacking in most studies cited in this presentation. Horowitz and Shapiro did both unilateral and bilateral masseterectomies and concluded that unilateral removal of the masseter results in severe skeletal alterations in the skull, jaws and dental arches while no marked gross or dental changes follow bilateral removal of the masseter muscle.

The detailed alterations observed after unilateral masseterectomy are of interest and excerpts from the summary of results follow:

> Skull. The rostrum deviates toward the unoperated side anterior to the fronto-nasal suture; both the nasal and the premaxillary bones are affected by this

change.

The sweep of the zygomatic arch is considerably reduced on the operated side; the entire arch is closer to the cranium, and the zygomatic bone proper is exceedingly thin. The anterior palatine foramina, usually found in bilaterally symmetrical locations in the control animals, varied in the operated animals; the foramen on the operated side lies further posterior than that of the unoperated side.

Mandible. The body of the mandible on the operated side bends sharply downward and laterally in the region of the third molar tooth; the angular process is blunt, and altered by a pronounced medial deflection; and a characteristic remodeling occurs in the ascending ramus, with corresponding alterations of the internal architecture. The mandible on the operated side is reduced in size, expecially in the superior-inferior dimensions of the ramus (from the sigmoid notch to the lower border); a smaller reduction in size is seen in the condyle-lower incisor alveolus length.

The dental arch. A "bowing" of the maxillary arch occurs on the operated side and the occlusal relationships of the teeth are severely affected on both sides. The first and second molar teeth of the maxilla and mandible do not occlude on the operated side, — "open bite"; the remaining molar teeth meet in a shearing manner, — "cross bite." The incisor teeth deviate toward the operated side.

The teeth of the operated animals, viewed under the dissecting microscope, show almost no evidence of attrition; extensive alveolar atrophy is apparent, especially in the region of the molar teeth.

Histologic examination of the periodontium and microscopic evaluation of the alveolar bone in the unilaterally masseterectomized rats also revealed alterations (Horowitz and Shapiro, 1956). An appearance of generalized disorganization in the atrophic periodontal membrane of the lower right (operated side) first molar was recorded. In occasional sections, localized mild inflammatory processes were observed, but there was no pocket formation.

A picture of generalized atrophy was also seen in the alveolar bone. The buccal wall was reduced to a thin shell of bone and resorption occurred in the interradicular septa. The crests of both buccal and lingual alveolar processes were resorbed apically for a considerable distance. None of these alterations were apparent in a digastric muscle resection group or in the control group animals. Unfortunately, the left (unoperated side) mandibular molar areas were not also studied to make the comparison possibilities complete.

A large study, comprising observations on 37 dogs, 19 cats, and 4 rhesus monkeys, of the effects of extirpation of the masseter and temporalis, and removal of tooth tubercles, was completed by Nikitjuk (1968). Metrical assessments, vital stain bone marking and fissure line representation techniques were used.

The comparison of the results of this study with research that had been previously reported yielded interesting discussion regarding the mechanism responsible for growth alterations. One such analysis was based on Scott's (1957) statement that the relative amount of sutural growth decreases with age while the relative amount of apposition on flat bone surfaces increases. Nikitjuk found greater growth on the operated side in young animals, an equalization of growth rates of operated and unoperated sides with increasing age and less growth on the operated side in older animals. Most authors have reported decreased growth on the operated side. According to Nikitjuk, this may be viewed as a simplification due to a lack of observation of the early growth periods. To explain these age linked growth alterations, Nikitjuk suggests that (1) the operated side undergoes a decrease in functional stress while the unoperated side undergoes an increase and (2) pressure increases result in a slower growth rate at sutures but an accelerated rate of apposition on flat surfaces due to increased lateral tension in the periosteum. If these two postulates are accepted along with Scott's statement then an explanation of the mechanisms accounting for the observed altered growth rates is possible. In young animals, where sutural growth predominates, a decrease in functional stress would favorably affect the growth rate of the operated side. In older animals, where flat surface growth is more prolific, the same decrease in functional stress would yield less growth for the operated side.

MOLAR EXTRACTION OR REDUCTION

A classical presentation by Baker (1922) was concerned with observations derived from a series of experiments utilizing small numbers of rabbits, sheep, etc. The paper was read to propose a viewpoint and generate interest in the subject of craniofacial alterations due to interference with masticatory activity resulting from tooth reduction. Unfortunately, numerous misrepresentations occur throughout the presentation. The problems of providing correct orientation lines in a subjective analysis of an object as complex as the skull were well illustrated in Baker's photographs. A five gram difference in skull weight in animals whose total skull weight is 248 grams must be statistically insignificant and is a poor basis for a conclusion regarding reduced skull weight in operated animals. A comparison of an ewe with her lambs neglects the importance of their age difference. The finding that "7,050 pounds of pressure were exerted on the bones of the skull through the medium of the teeth in masticating (a lean corned beef sandwich)" also prompts reflection regarding the authors intention.

McFee and Kronman (1969) provided a more scientific basis for assessment of the alterations in maturing rabbits by using metallic implants and cephalometric radiography. They determined that the snout was the major region of growth (in 65 day-old rabbits) which was directed anteroposteriorly. Growth of the snout was impaired after obliteration of posterior and anterior teeth on the right side. A tendency toward deviation of the midline toward the untreated side was observed.

The process of extraction wound healing has been studied by numerous authors in a variety of species. Pietrokovski and Massler (1967) gave an account of findings after rat molar extractions. They found that the rate of healing was the same whether one or two adjacent molar teeth were removed. Healing was slower in the maxilla as compared to the mandible. The alveolar crest resorbed after tooth extraction while the socket region filled in with new bone at its base. The retention of root remnants (a common occurrence in rat molar extraction due to hypercementosis) delayed and altered the healing process. Exfoliation was in progress accompanied by cementum apposition.

The general changes in the jaws following tooth extraction (not limited to healing of the tooth socket) were studied by Astrand and Carlsson (1969) using the techniques of histology and fluorescence microscopy after administration of tetracycline. The formation of bone outside the sockets was localized to the basal bone layer which forms the upper limit of the maxillary alveolar process in the rat. This ossification appeared to begin about 3 days after extraction and to continue for about a week. It was usually restricted to the area opposite the socket of the extracted tooth and might be a compensatory process, whereby the alveolar process is reinforced after loss of the tooth.

Koivumaa (1961) reported periodontal pockets, tooth mobility and gingivitis on the non-extraction side which was ascribed to overloading mastication. Some cases did not show these changes suggesting an individual susceptibility. Changes in the periodontium of teeth without antagonists were more frequent and serious. The masseter muscle (but not the temporal) of the operated side was found to be atrophic.

Other Variables

Numerous other types of changes in the "normal" life style have been demonstrated to play a role in structural modifications. Watt and Williams (1957) disclosed that the physical consistency of food affected the growth and development of the mandible and maxilla of the rat. Heston (1938) discovered rostral deviations (not side specific) in rats fed a diet having an extensively altered calcium to phosphorous ratio. Selman and Sarnat (1953) extirpated the frontonasal suture of the rabbit and disclosed findings in agreement with Nikitjuk's hypothesis presented earlier.

MATERIALS AND METHODS

I. SAMPLE

The sample consisted of 26 to 38 normal[1] and 30 "experimental" Long-Evans strain male rats. The experimental animals were divided into three groups of ten animals each; a masseterectomy group, a sham operation group, and an extraction group.

The starting weight of each animal was 90 ± 3 gm. except for the members of the extraction group whose starting weight was 145 ± 3 gm. to allow time for the eruption of third molar teeth. The corresponding ages are circa 30 and 40 days, respectively. Animals demonstrating regular daily weight gains were selected shortly after weaning. Many of these were littermates so the sample was as homogeneous as possible.

During the study period of 77 days for the normal group and 74 days for the experimental groups, animal weights were recorded and the growth curves were expected to approximate a linear configuration. The rats were maintained on a diet of Purina Laboratory Rat Chow and

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[1] S.H. Jacobson. 1969. Mandibular Growth in the Rat. Master's Thesis, University of Manitoba.

J.F. Cleall. 1971. Growth of the craniofacial complex in the rat. Amer. J. Ortho., 60:368-381.

water ad libitum, and no alterations to the hard pellets were made for the benefit of operated animals. Table I summarizes the animal groupings.

TABLE I

ANIMAL GROUPS

Group	Number of Animals	Starting Weight
Normal Cranium*	26	90 ± 3 gm.
Normal Mandible**	38	90 ± 3 gm.
Masseterectomy	10	90 ± 3 gm.
Sham Operation	10	90 ± 3 gm.
Extraction	10	145 ± 3 gm.

*J.F. Cleall, op. cit.

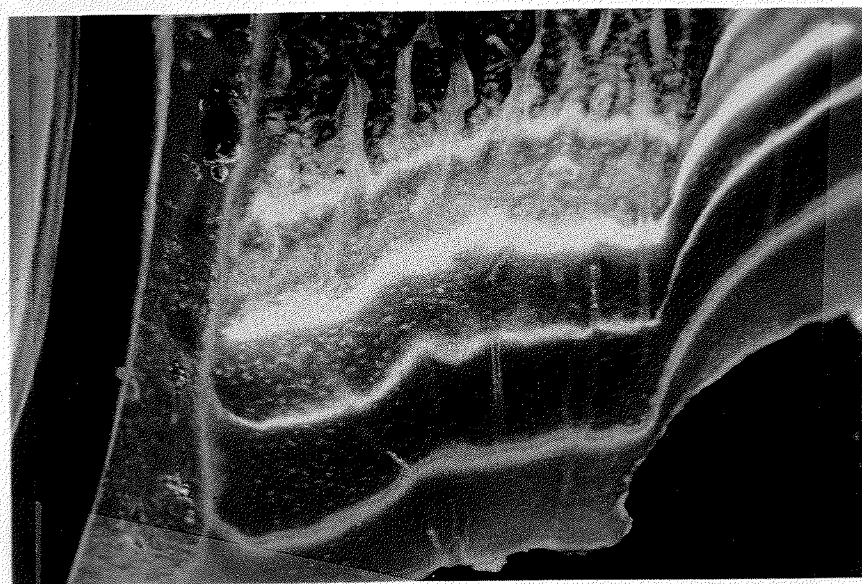
**S.H. Jacobson, op. cit.

II. VITAL STAINING

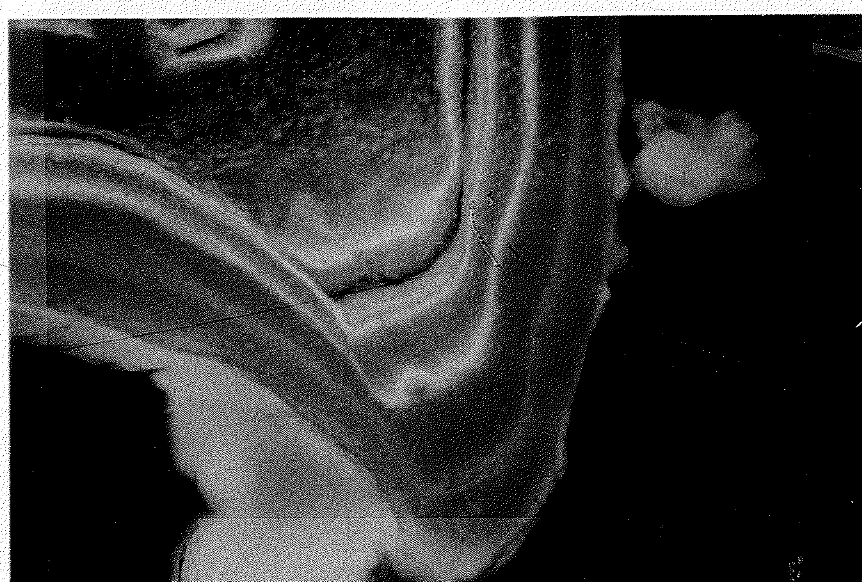
A series of five vital stain lines was achieved by intraperitoneal injection of oxytetracycline, alizarin red S, trypan blue, or combinations of these at the intervals and dosages shown in Table II.

Two stain line sequences were used. The second sequence omitted the use of trypan blue which was difficult to visualize under ultra-violet light and required the injection of a larger fluid volume than tetracycline or

Appositional Growth



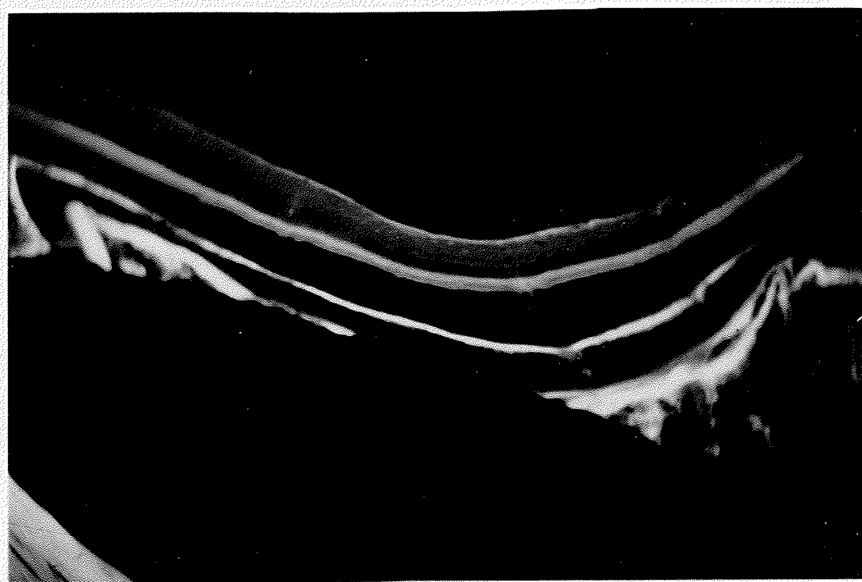
Typical Stain Line Contours at Cranium Site 22.



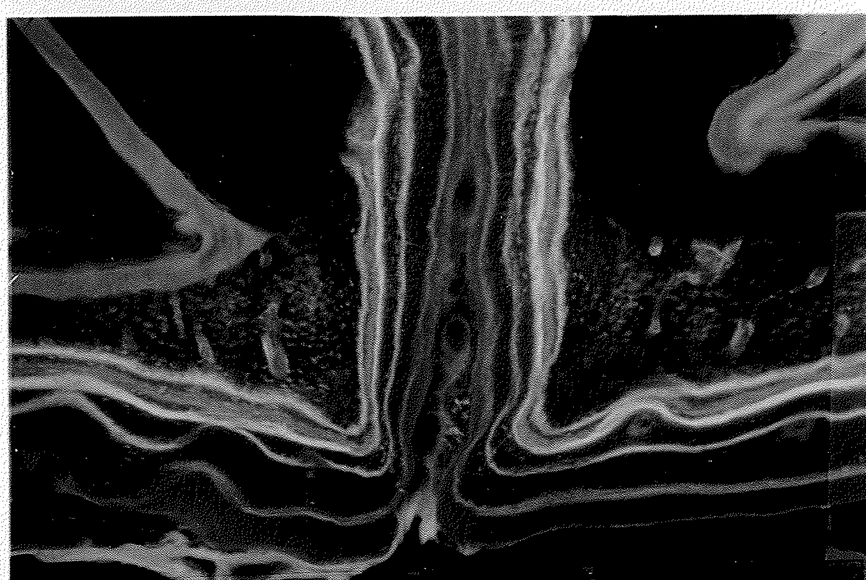
Typical Stain Line Contours at Cranium Site 14.

Figure 1. Photomicrographs of Stain Lines.

Apposition and Resorption



Typical Stain Line Contours at Mandible Site 24.



Typical Stain Line Contours at Cranium Site 7.

Figure 2. Photomicrographs of Stain Lines.

TABLE II

VITAL STAINING

SEQUENCE 1.

Stain Line	Code	Injection Day	Dosage
Terramycin (Oxytetracycline)	A	Day 0	70 mg./kg.
Alizarin Red S (2% Solution)	B	Day 4	300 mg./kg.
Trypan Blue	C	Day 11	350 mg./kg.
Terramycin + Alizarin	D	Day 25	70 mg./kg. 200 mg./kg.
Terramycin + Trypan Blue	E	Day 46	70 mg./kg. 350 mg./kg.
Bone Edge (No Stain)	F	Day 74(Expt'l) Day 77(Control)	Sacrifice

SEQUENCE 2.

Stain Line	Code	Injection Day	Dosage
Terramycin (Oxytetracycline)	A	Day 0	70 mg./kg.
Alizarin Red S (2% Solution)	B	Day 4	300 mg./kg.
Terramycin + Alizarin	C	Day 11	70 mg./kg. 200 mg./kg.
Terramycin	D	Day 25	70 mg./kg.
Alizarin	E	Day 46	250 mg./kg.
Bone Edge (No Stain)	F	Day 74	Sacrifice

alizarin red S. The first stain sequence was used for the control group, masseterectomy group and part of the sham operation group. The second sequence was used for the extraction group and the remainder of the sham group. The use of different stain sequence was not expected to influence the results of the study.

The determination of appropriate stain dosages and the effect of these agents on bone growth has been described elsewhere (Cleall et al., 1964).

If a growing bone surface is sectioned at right angles after vital staining, a thin line (representative of bone deposited while the stain was in the circulation) is visible. As the plane of sectioning deviates from 90 degrees to the bone surface, the width of the stain line increases, thereby complicating the interpretation and measurement of stain markings. A degree of operator experience is required to obtain reliable measurements.

III. SURGICAL PROCEDURES

Masseterectomy

On Day 2 of their study period, one group of rats had the entire right masseter muscle removed under Nembutol anaesthesia (35 mg./kg.). The procedure was as follows:

1. A skin incision 2 cm. long was made running parallel to, and below the zygomatic arch from below the

ear to 5 mm. from the corner of the mouth.

2. Blunt dissection of the underlying fascia allowed retraction of two flaps using elastics sutured to the flaps and held to the edges of the operating board. This was the only stabilization and was used to minimize the chance of interference with respiration.

3. Blunt dissection of the anterior superficial head of the muscle, and severance of its anterior ligamentous insertion allowed reflection of this portion to reveal the underlying anterior deep head which was sectioned just beneath the zygomatic arch.

4. The posterior superficial and posterior deep heads were separated from the zygomatic arch by an incision along its inferior border so placed as to ensure that the periosteum remained undisturbed.

5. The muscle mass now remained attached only on the lower border and angle of the mandible and was cut close to the bone with scissors.

6. The marginal mandibular and buccal branches of the facial nerve were removed with the muscle because of their close fascial attachment to its surface. Care was taken not to injure the facial artery or perforate the buccal membrane.

7. Three interrupted sutures were placed to close the site and post-operative recovery was rapid.

Sham Masseterectomy

The sham operation group of rats was subjected to a procedure of skin incision and flap retraction; facial nerve transsection (marginal mandibular and buccal branches); stimulation of localized bleeding and wound closure. The operation was carried out on the right side only. The intent of these procedures was to ascertain what contribution to the disturbances observed in the masseterectomy group was provided by features of the surgical intervention other than muscle removal.

Extraction

On the first day of the study period; the maxillary right first, second, and third molars were extracted in the third group of experimental animals. The use of a paper-clip mouthprop and specially adapted forceps made the removal of these teeth relatively simple in spite of the physiological hypercementosis of roots which necessitated delicate luxation lest the roots be fractured. Nembutol anaesthesia was used.

IV. SPECIMEN PREPARATION

At the conclusion of the study period, the animals were sacrificed by decapitation under ether anaesthesia. The heads were placed in a pressure cooker at 30 lb./sq. in.

for five minutes. After the soft tissues were removed from the bones, the cleaned crania and mandible halves were stored in 70 per cent ethyl alcohol.

Embedding Procedure

1. The dried specimen was placed in Bioplastic[2] liquid (polymer) overnight to allow complete penetration into cavities and the escape of air bubbles.

2. Forms of appropriate size were made from tin foil. A layer of Bioplastic liquid and catalyst (monomer) was allowed to harden in the floor of the form.

3. The specimen was lifted from the Bioplastic liquid, drained briefly and oriented in the form. A mixture of liquid and catalyst were added to fill the form once the specimen was stabilized.

4. After initial setting, the block was cured at 65^{o}C. for one day.

Sectioning

A Gillings-Hamco Thin Sectioning machine with a diamond wheel[3] was used to cut coronal sections of the undecalcified rat crania and cross sections of the

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[2]Bioplastic (Ward's Plastic Center Incorporated, Rochester, New York 14606).

[3]Gillings-Hamco, Rochester 20, New York.

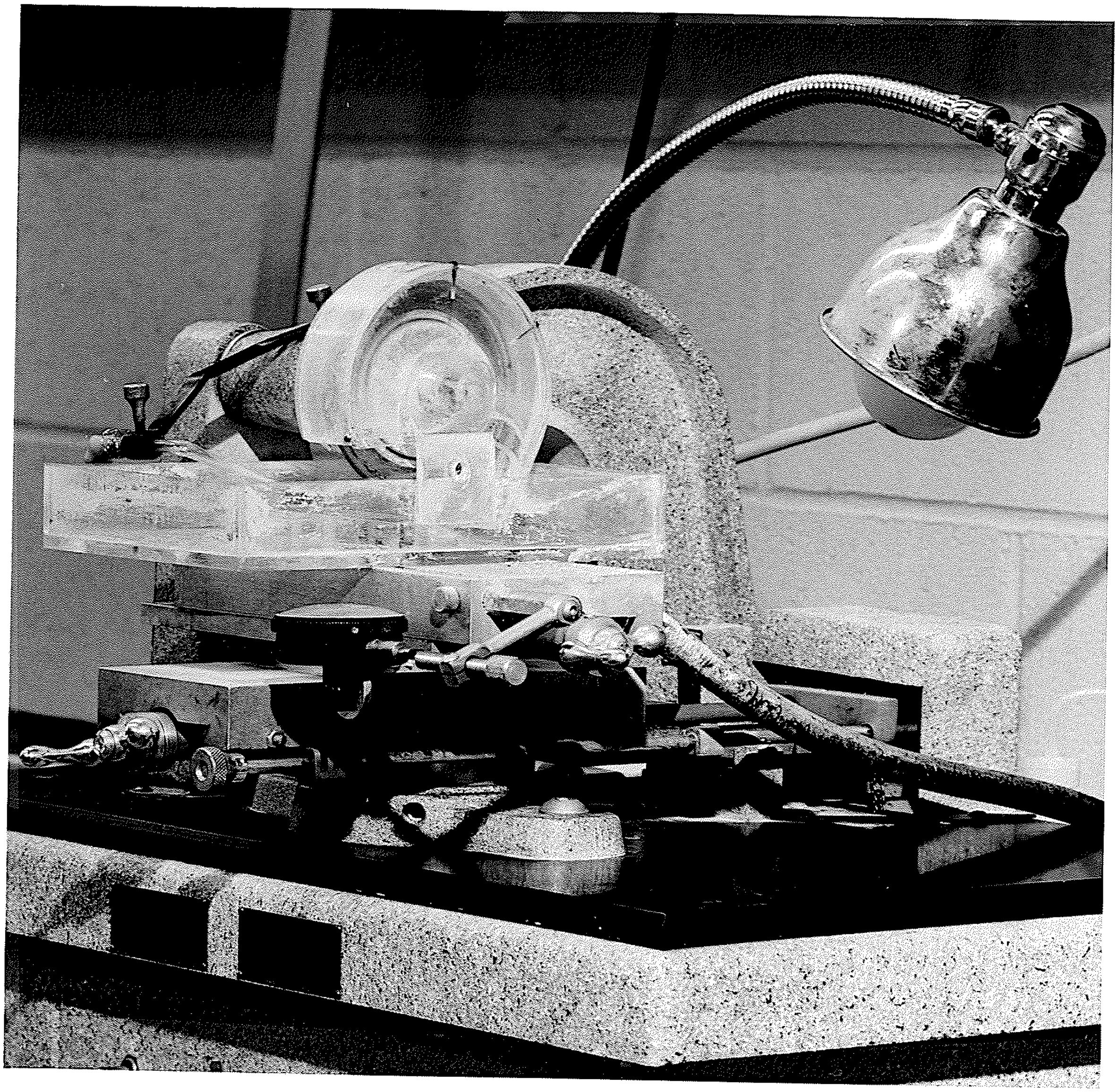

Figure 3. Gillings-Hamco Thin Sectioning Machine.

mandible halves. The plastic blocks were prepared for this step by trimming, polishing, scoring guidelines and mounting on a plastic holder in proper orientation. Sections of 120 to 180 microns and of an area suitable for mounting on microscope slides under a glass cover were produced.

Seven regions, determined by anatomical landmarks, were chosen for study in the cranium. Three consecutive sections were taken in each region. Similarily, six regions were chosen for study of the mandible halves with two sections representing each region. Figure 8 illustrates the areas of sectioning and their designations. It will be noted that all sections of the cranium were cut in the coronal plane. The mandibular sections, however, are cross sections cut at right angles to a line tangent to the inferior border and angular process of the mandibular half.

V. MEASUREMENT

The slides were examined using a Zeiss Standard Research GSL microscope with both ultraviolet and tungsten light sources. The microscope was also equipped with an eyepiece scale, a calibrated microscope stage and suitable filtering systems.

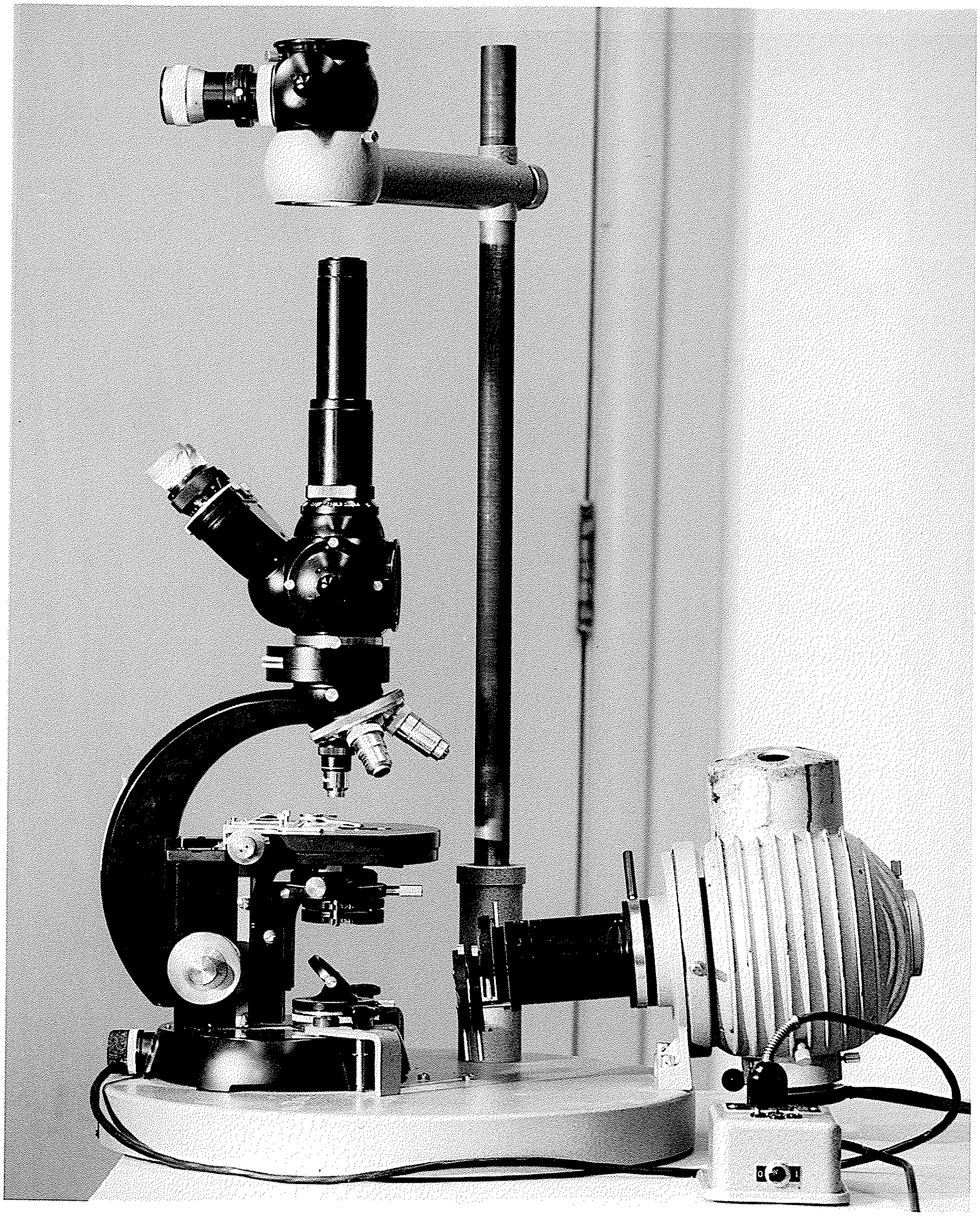

Figure 4. Zeiss GSL Microscope with Ultraviolet Light Source.

In each region of sectioning, a number of sites were selected which could be determined by reference to anatomical landmarks so that the error of relocation was minimal.

For each side of the animal, there were 58 sites studied in the sections of the cranium and 30 sites studied in the mandibular sections. Left and right sides were evaluated independently for the experimental groups. The control values assumed symmetry and were obtained from studies of the normal growth of rat crania and mandibles computed by Cleall, 1970, and Jacobson, 1970.

Linear Analysis

The eyepiece scale, which was graduated in units of 5 microns at the magnification used, ranged from 0 to 500 units. The stain line intervals at each site were measured by first placing the 0 mark at the beginning of the first stain; then recording the scale values at the beginning of the subsequent stain lines and finally the bone edge in accumulative fashion. A computer program was used to change the five readings obtained into appropriate interval values. Table III shows the measurements made and the intervals calculated.

The measurement error of the linear analysis varies with the width of stain lines and the ability to relocate a measurement site. In ideal instances, the error was

±2.5 microns; ranging upwards to ±25 microns in sites posing interpretative difficulties. The majority of measurements were accurate to a tolerance of ±10 microns. This accuracy was far better than was required for the study.

The computer program for the linear analysis yielded the means, standard deviations, and standard errors for seven of the intervals produced by sequential staining as listed in Table III. Statistics were calculated for both operated and unoperated sides from progressive measurements for each animal. In addition, the mean differences between right and left sides for each of these measurements were calculated and a Student's t test applied to discover significant differences between sides.

TABLE III

LINEAR MEASUREMENTS

Stain Lines	Measurements	Intervals
A (Day 0)	--	--
B (Day 4)	AB	AB (4 Days)
C (Day 11)	AC	BC (7 Days)
D (Day 25)	AD	CD (14 Days)
E (Day 46)	AE	DE (21 Days)
F* (Day 74 or 77)	AF	EF (28 or 31 Days)
		AE (46 Days)
		AF (74 or 77 Days)

* Bone Edge.

Co-ordinate Analysis

The eyepiece scale was centered so that the 250 micron mark remained in the center of the field no matter how the scale was rotated. This mark was used to register the co-ordinate points at the first and final (A and E) stain lines at each site. The x and y co-ordinates were read from the vertical and horizontal Vernier scales of the microscope stage which were calibrated in 0.1 mm. The accuracy of the co-ordinates obtained was ±60 microns on both axes.

A computer program developed by Chebib and Cleall[4] (1970) allowed the mathematical superimpositioning of a series of co-ordinates on a standardized set of axes once a common origin and direction had been selected, thereby providing the mean co-ordinates and their standard deviation for the sample.

Polygons were constructed from the mean co-ordinates for each region of sectioning in each study group to allow graphical comparison of alterations in size and shape.

These polygons were produced by drawing a continuous line connecting the points determining the location of the initial (A line polygon) or final (E line polygon) stain lines at each site in the particular section in question.

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[4]Cleall,J.F. and Chebib,F.S. 1971. Coordinate analysis applied to orthodontic studies. Angle Ortho. Vol. 41, #3, 214-218.

CODES

In order to improve legibility, a number of abbreviations will be used to denote the various sides of the study groups. The study groups are the normal group, masseterectomy group, sham operation group and extraction group. When the term "experimental groups" is used, it refers to all but the normal group. Each of the experimental groups was further subdivided into the operated side (right side) and the unoperated side (left side) since the measurements for sites were compared independently. The abbreviations for these divisions are:

NORM - Normal Group
MAS - Masseterectomy Group (no side distinction)
MASR - Operated side of the Masseterectomy Group
MASL - Unoperated side of the Masseterectomy Group
SHAM - Sham Operation Group (no side distinction)
SHAR - Operated side of the Sham Group
SHAL - Unoperated side of the Sham Group
EXT - Extraction Group (no side distinction)
EXTR - Operated side of the Extraction Group
EXTL - Unoperated side of the Extraction Group

The abbreviations for the seven stain line intervals have been illustrated in Table III. These codes will be utilized in Figures, Tables and in the text with no further explanation.

CHAPTER IV

RESULTS

GENERAL OBSERVATIONS

Growth Curves

Comparison of the growth curves obtained from plotting the data of the linear analysis for each of the 88 sites studied revealed a dominant pattern that was observed at the majority of sites. The behavior of the growth curves of each group studied was typical as was the relationship of the curves of the various groups to each other. The tendency to follow the pattern was exhibited by both mandibular and cranial growth curves. When exceptions to the basic pattern occurred, either within a group or between groups, then an occasion of specific influence rather than generalized growth alteration was recognized.

Normal. The basic pattern is illustrated by the growth curve drawn in Figure 5. The first interval (AB) represented the ending of a growth spurt in the normal group which corresponded well with the completion of the dentition by the eruption of the third molar teeth at an age of approximately forty days. The succeeding stain line intervals (BC, CD, DE, and EF) showed relatively steady daily increments of bone deposition with a magnitude dependent on the particular site location. The result was an almost

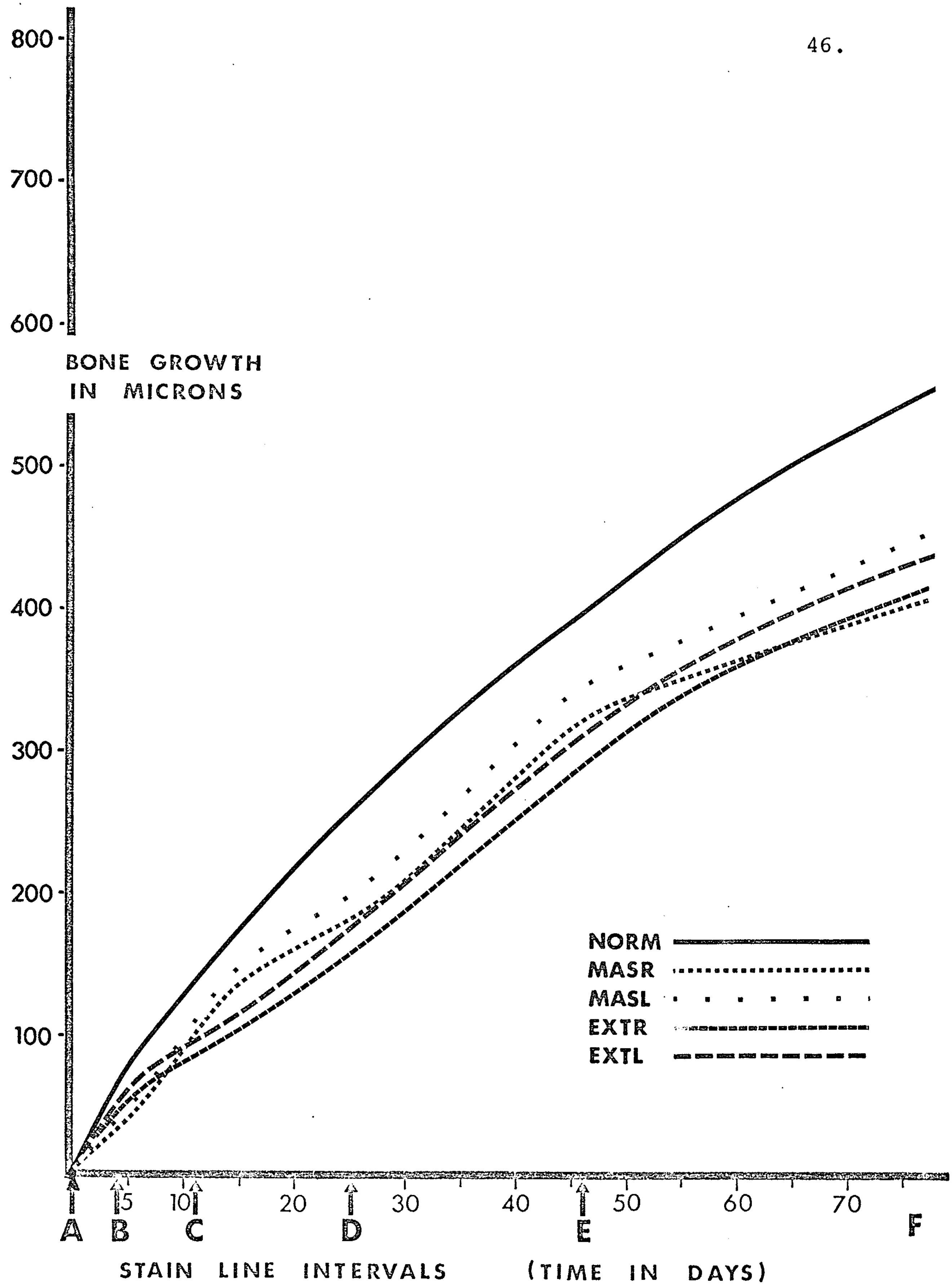


Figure 5. General Patterns of Bone Growth Curves.

linear growth curve for this period with a tendency for a gradual growth rate decline as the experimental period progressed. This tendency was most marked in the final interval. Left and right sides were assumed to be growing at the same rate in the normal group and were represented by a single curve.

Masseterectomy. Each of the experimental groups demonstrated a different growth curve pattern. The masseterectomy group curves showed a biphasic response. It began with an initial rate much less than normal during the AB interval followed by an accelerated rate in the BC interval which regularly surpassed the normal rate. Another period of rate decrease occurred in the CD interval followed by an acceleration in the DE interval and a final rate decline during the EF interval. The alternating periods of decreased and increased apposition rate resulted in a total bone deposition that was less than normal. The bisection of the oscillating masseterectomy curve would yield a net growth curve of gradually decreasing slope. When compared to the normal curve an increasing rate disparity would be observed with the progression of time. The periods of acceleration of bone deposition (which can be interpreted as an attempt to compensate for the periods of retardation) were not sufficient to prevent the overall decrease in bone apposition.

The Duncan Multiple Range Test was used to determine the statistical significance of the growth increment differences between groups for each stain line interval. The alternate increments of growth in the masseterectomy group were either significantly less or more than normal; usually at the 1 per cent level of confidence.

There were growth rate differences between the operated and unoperated sides of the masseterectomy group which also demonstrated a "catch up" pattern, as the growth curves of the sides neared or crossed each other; but the overall effect was one of less growth on the operated side. The side differences were usually small and not statistically significant. When a side difference of significance was observed it was an important finding related to a specific type of growth alteration at the site concerned.

<u>Sham</u>. The growth curves of the sham operation group approximated the normal curve more closely than those of the masseterectomy or extraction groups. The total growth of the sham group was usually not significantly different from normal. There was, however, greater variability in the relationship of sham to normal curves than in the relationship of other experimental groups to normal curves. The sham group curves demonstrated a variety of patterns in relation to the normal.

1. A period of early decline in rate was followed

by accelerated deposition during the second half of the experimental period often yielding total growth values slightly larger than normal.

2. A period of early growth acceleration of a mild degree ended in a marked rate decline during the EF interval resulting in overall growth slightly less than normal.

3. The sham group curves demonstrated a rate less than normal but greater than that of the masseterectomy group or extraction group.

Because of the variety of general growth responses demonstrated by the sham group (all of which were not critical in the overall analysis since they yielded total growth values which were usually not significantly different from normal) the sham group curves have been omitted from Figure 5. Significant differences from normal did occur during the most rapid periods of rate change of sham group apposition.

The rate differences between the operated and unoperated sides of the sham group were commonly small and not statistically significant. Rare instances of important side differences were found at sites near direct surgical intervention.

Extraction. At many of the sites the extraction group curves showed the slowest overall rate of bone apposition of all the groups studied. The AB increment was usually larger than that of the masseterectomy group but smaller than normal. There followed a decline in rate during the BC interval and a recovery marked by an increase in rate to approximately normal value for the CD interval. The decline in rate that occurred during the DE and EF intervals was more marked than normal decline. Substantial differences between extraction and normal group increments were statistically significant at the 1 per cent level for most of the sites studied. The rates during the AB and BC intervals often approximated the normal value and were not significantly different.

In general, the operated side of the extraction group grew less than the unoperated side but these differences were slight. Side differences of statistical significance were confined to sites directly affected by surgical intervention.

The starting weight of the extraction group (145 gm.) was larger than that of the other groups (90 gm.). The possibility of a contribution to the finding of retarded growth in the extraction group due to slower apposition in an older age range was investigated. Examination of weight gain curves for the normal group revealed that normal animals achieved a weight of 145 gm. on about the sixth day of the experimental period. The sixth day value on the normal curve was taken as the starting point for the extraction group and the growth curves of the extraction group were adjusted for a selection of sites to eliminate the age difference. It was found that such adjustment brought the extraction curves graphically closer to the normal curve. The starting sector of the extraction curve (the original AB interval) now was coincident with the normal curve but the overall growth rate differential was not altered appreciably. This was possible because both normal and extraction curves approximated linearity to about the same extent and an adjustment of six days in a period of seventy-four was insignificant. The total amount of bone deposition registered for the extraction group was somewhat increased by the age correction, but not enough to influence the significance or interpretation of findings obtained without the age correction.

On the basis of these comparisons, it was decided to retain the rate comparison values obtained for the extraction group without utilizing the age correction. When viewing the graphs it should be kept in mind that the slope of the AB interval of the extraction group is best compared to the slope of the BC interval of the normal group, and that the graphical separation of normal and extraction curves is somewhat exaggerated.

WEIGHT GAIN

The curves plotted as weight against time for the various study groups revealed a pattern similar to the general patterns of skeletal growth curves. The entry into a slower phase of growth at approximately 35 days of age (BC interval) was observed as a decline in the weight gain rate at the same time. The weight curves were much more erratic than the bone apposition curves. Weight loss was noted after vital stain injections but was quickly recovered in a "catch up" phase. A similar recovery was never as complete for skeletal measurements.

The mean weights at the time of the fifth stain injection for the various groups were as follows: normal group 274 gm., sham operation group 286 gm., masseterectomy group 254 gm., and extraction group 265 gm. (adjusted for initial difference). These weights reflect the relative general bone growth findings. The Student's t test for statistically significant differences was applied but none of the weight differentials were significant.

ANTEROPOSTERIOR GROWTH

One of the problems associated with a study of stains in the coronal plane is the lack of direct assessment of growth in the third dimension. A most important consideration to be kept in mind when inspecting the apparent growth increments in the lateral direction is the effect of the area relocation process due to growth in the anteroposterior direction. The various regions of sectioning were selected by the location of anatomical landmarks at the end of the experimental period. This procedure did not allow the sectioning of the same region of "initial bone" in animals growing at different rates in the anteroposterior dimension.

Consider the hemimandible which is a single bone. A metallic implant placed in the Retromolar Region (just above the antegonial notch) at the beginning of the experimental period would be found located anteriorly and superiorly in relation to the same anatomical location on the enlarged hemimandible at the end of the experimental period. The section made through the antegonial notch (Retromolar Region) at the end of the experiment would not contain the implant, that is, the bone which occupied the precise antegonial notch position at the start of the experiment.

The linear measurements which were made between stain lines are therefore not an assessment of direct lateral bone apposition but the measurement of the lateral resultant of an oblique growth direction ending in the region sectioned at the conclusion of the experimental period. The degree of obliqueness of the growth direction is dependent on the amount of anteroposterior growth.

The coordinate analysis polygons provided a graphical manifestation of this consideration. If all the study animals (that were the same size initially) grew at the same rate in the anteroposterior direction, then the coordinate polygons representing the initial stain line position at the study sites in a particular region would be identical. However, it was found that the mandibular A line polygons could not be superimposed for the experimental groups (Figure 6). Varying growth rates were observed and held responsible for this finding.

The coronal sections of the cranium reveal a number of sutural connections which allowed the translation of bones in relation to each other. As might be expected, the A line polygons showed even less similarity for the cranial regions (Figure 7).

First Molar Region XIII

(Anteroposterior View)

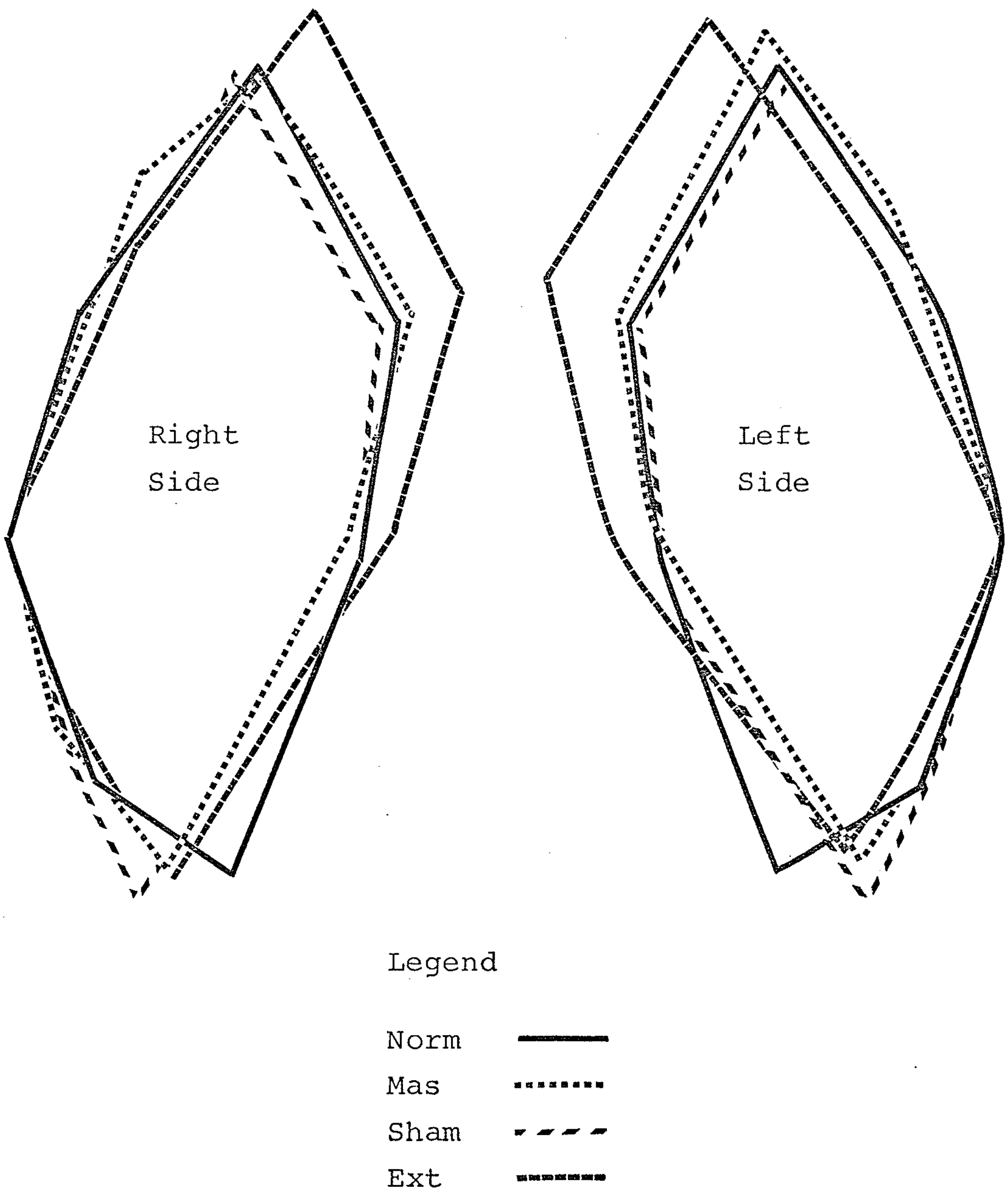


Figure 6. Mandibular A Line Polygons.

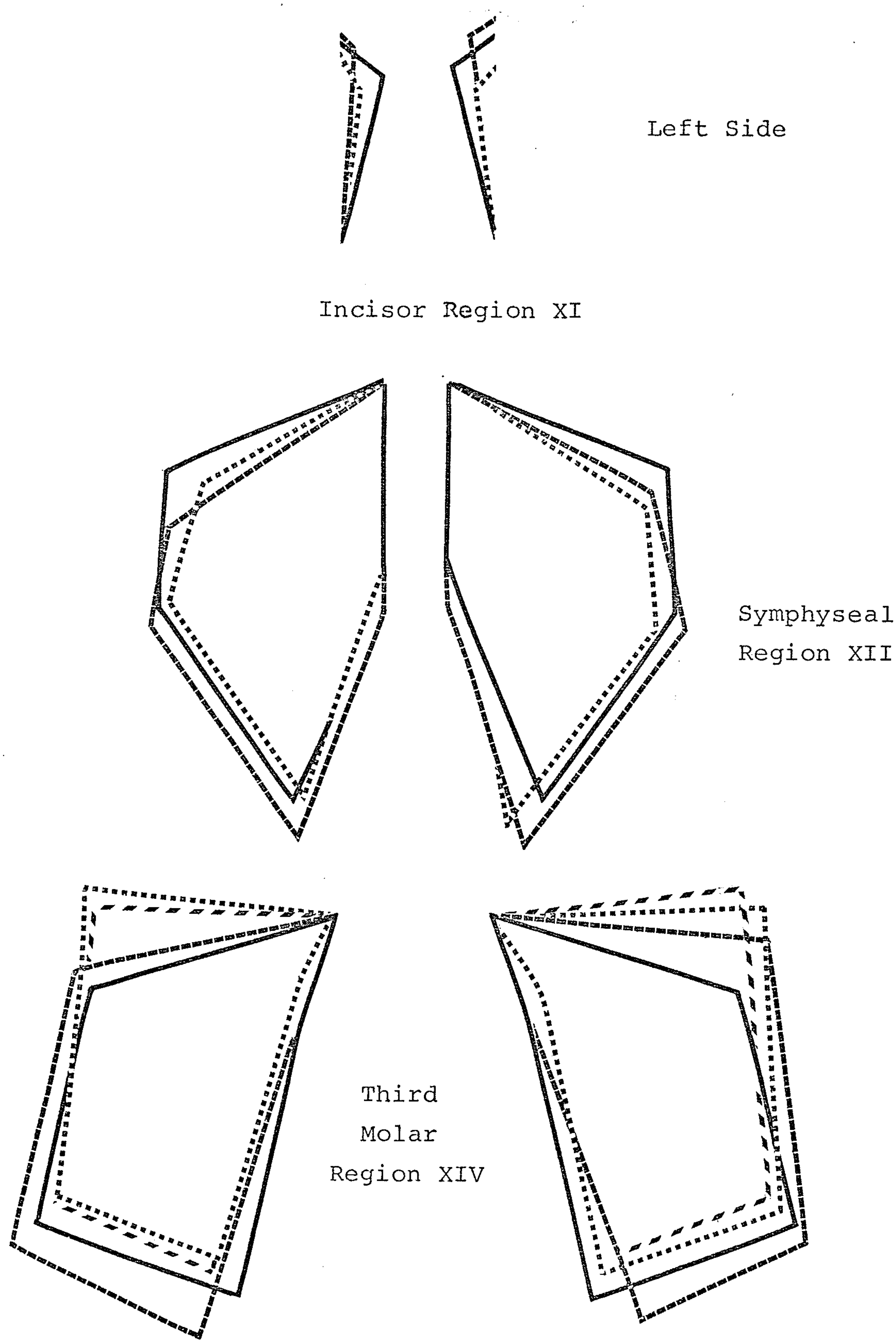


Figure 6. (CONTINUED)

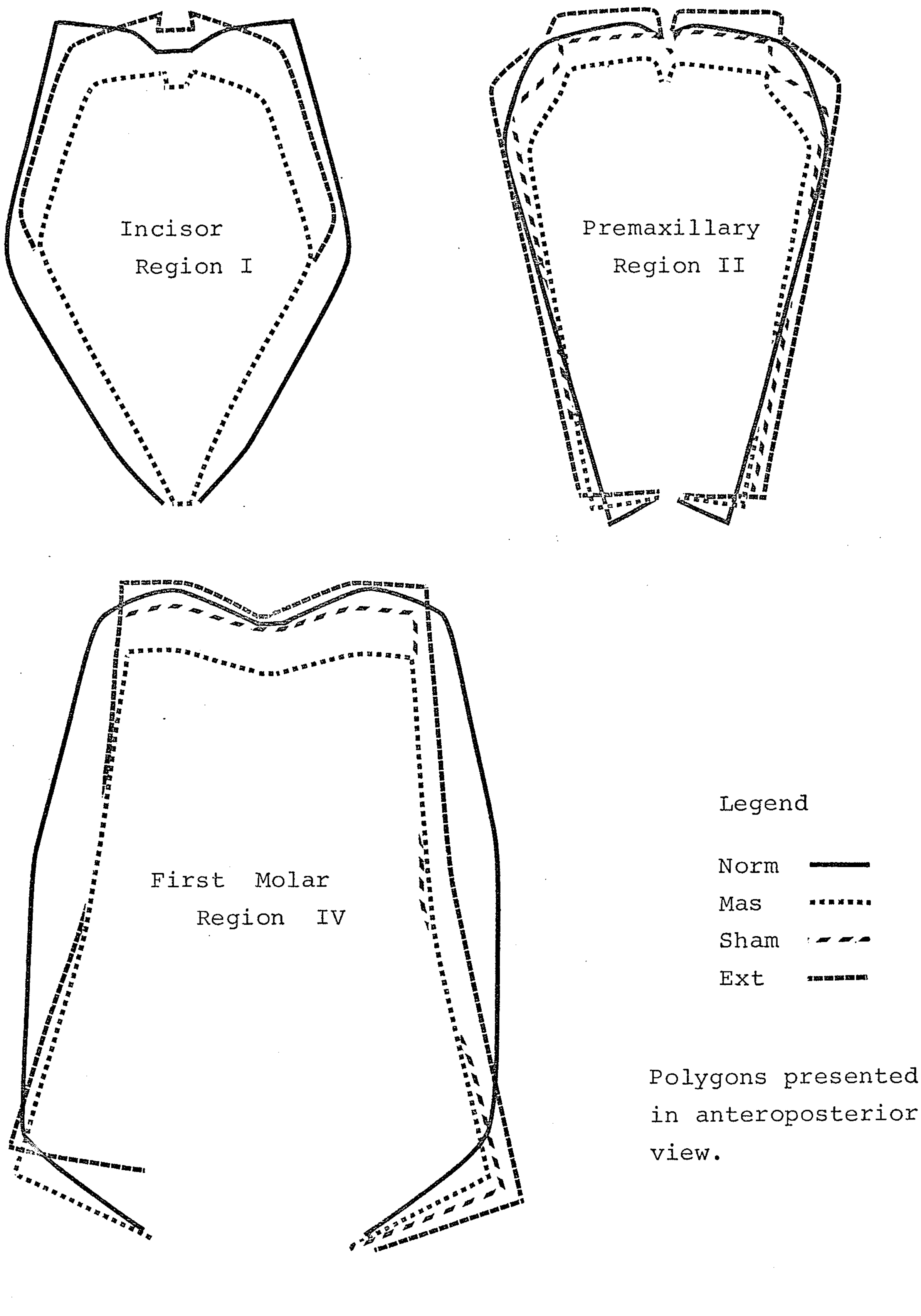


Figure 7. Cranial A Line Polygons.

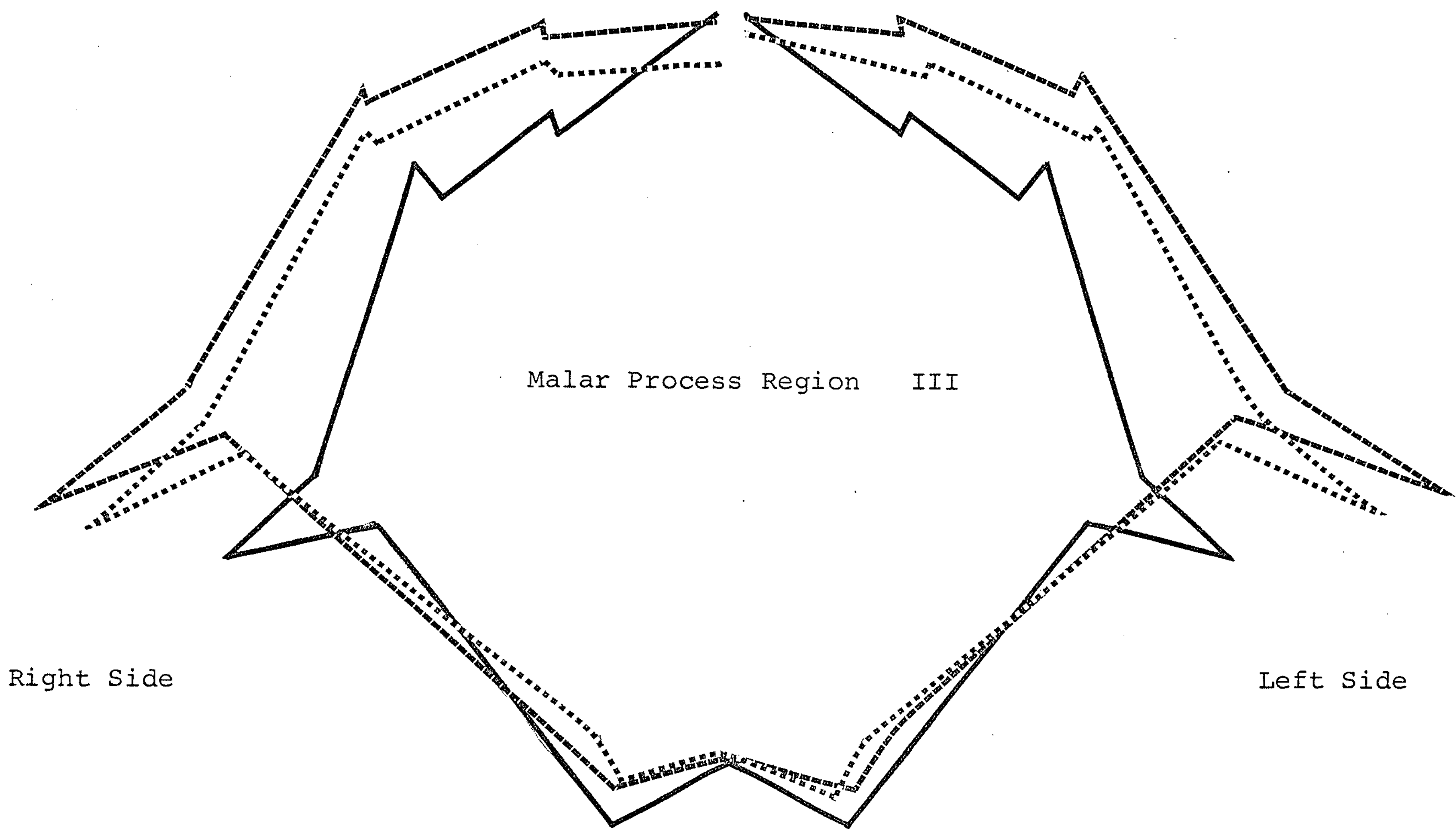
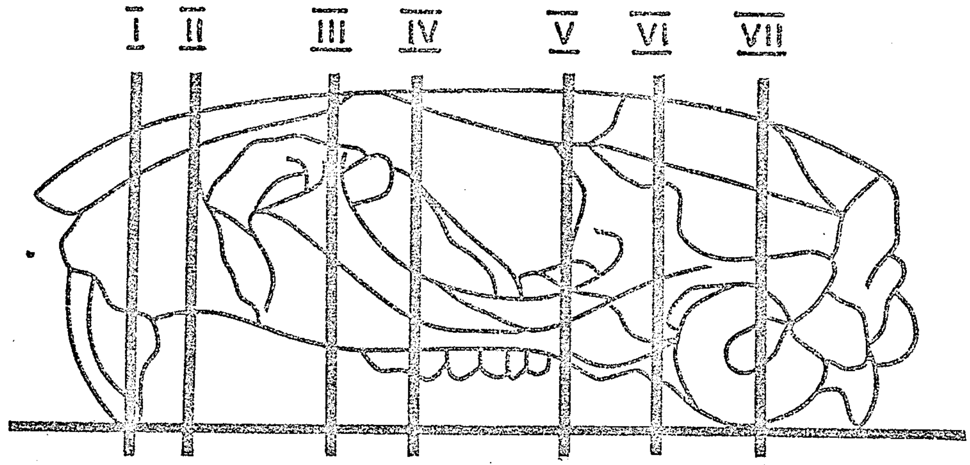


Figure 7. (CONTINUED)

GROWTH SITES

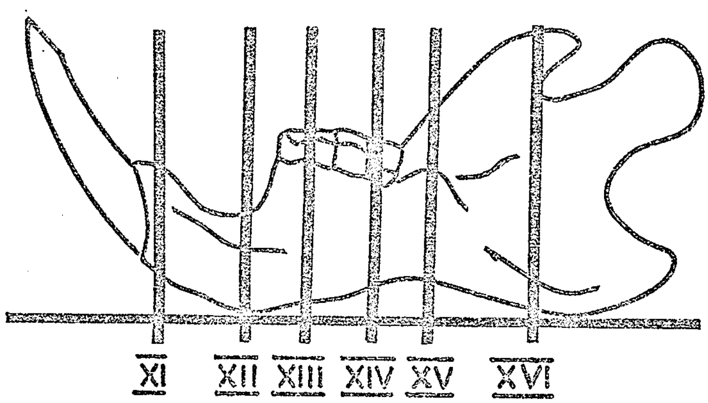
The regions of sectioning were selected at the end of the experimental period by reference to anatomical landmarks and were located and named as illustrated in Figure 8. In each region a number of sites were selected according to the standardized technique and these are numbered and located in Figures 9 to 21, inclusive. These diagrams of each region illustrate the typical outline and normal bone growth patterns. The stain lines are lettered in accordance with Table II.

To facilitate the reading of the results, removable sheets showing composites of the diagrams for cranial and mandibular sections have been included. Site locations are numbered from one to thirty in the mandibular cross sections and from one to fifty-eight in the cranial coronal sections from anterior regions to posterior regions.



CRANIUM CORONAL SECTIONS

I INCISOR REGION
II PREMAXILLARY REGION
III MALAR PROCESS REGION
IV FIRST MOLAR REGION
V ZYGOMATIC REGION
VI SQUAMA TEMPORAL REGION
VII TYMPANIC BULLA REGION



MANDIBULAR CROSS-SECTIONS

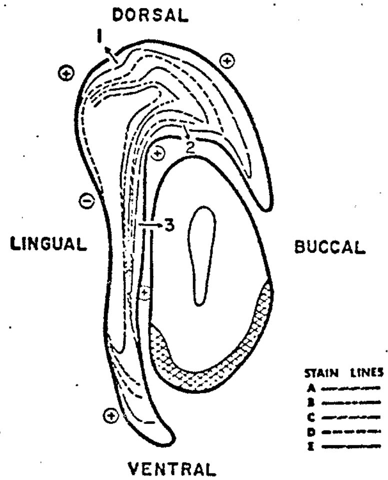
XI SYMPHYSEAL REGION
XII POST SYMPHYSEAL REGION
XIII FIRST MOLAR REGION
XIV THIRD MOLAR REGION
XV RETROMOLAR REGION
XVI RAMUS REGION

Figure 8. Regions of Sectioning.

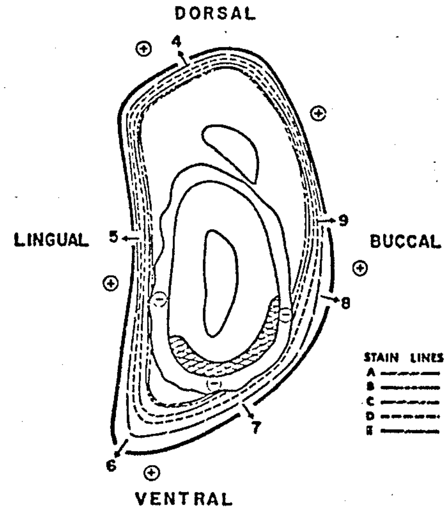
REMOVABLE COMPOSITE CHARTS
OF CRANIAL AND MANDIBULAR REGIONS

MANDIBULAR CROSS SECTIONS

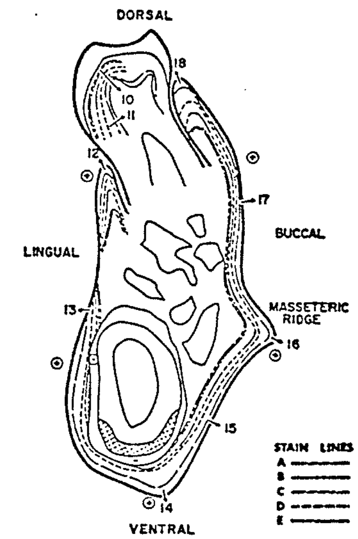
SYMPHYSEAL REGION



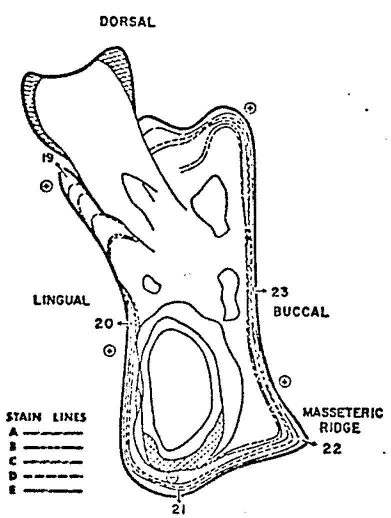
POST SYMPHYSEAL REGION



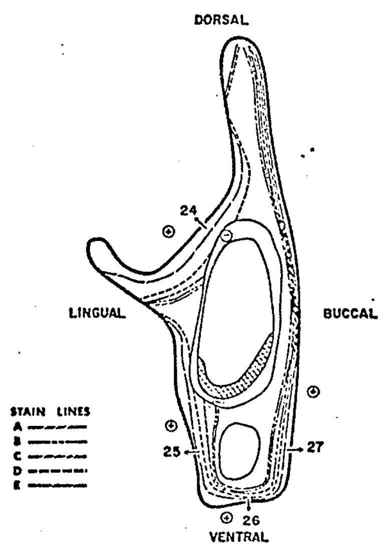
FIRST MOLAR REGION



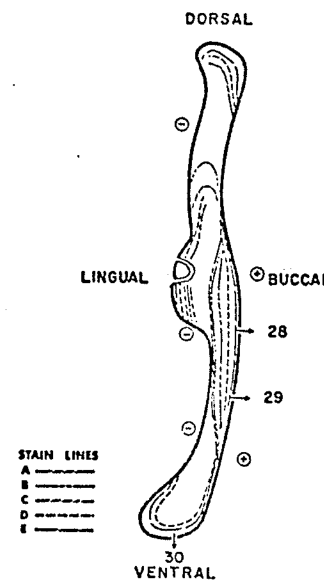
THIRD MOLAR REGION



RETROMOLAR REGION

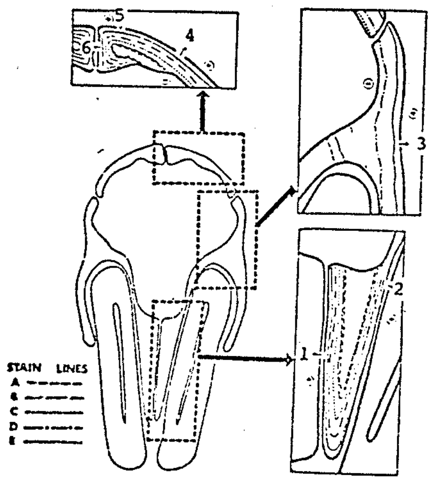


RAMUS REGION

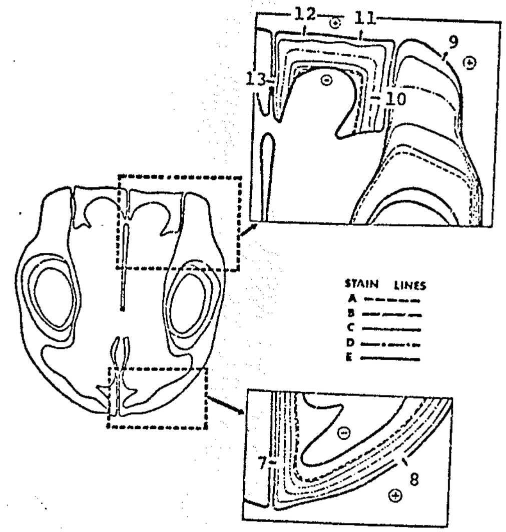


CRANIAL CORONAL SECTIONS

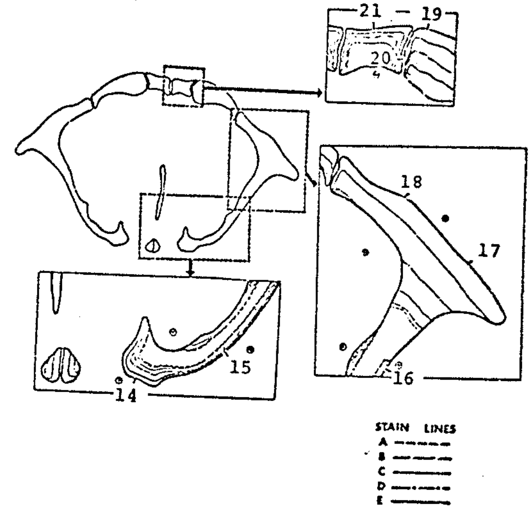
INCISOR REGION



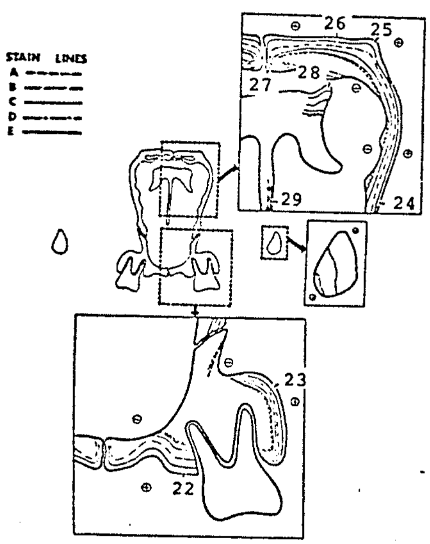
PREMAXILLARY REGION



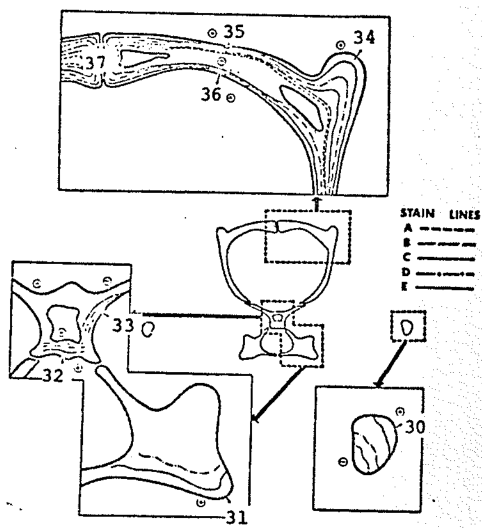
MALAR PROCESS REGION



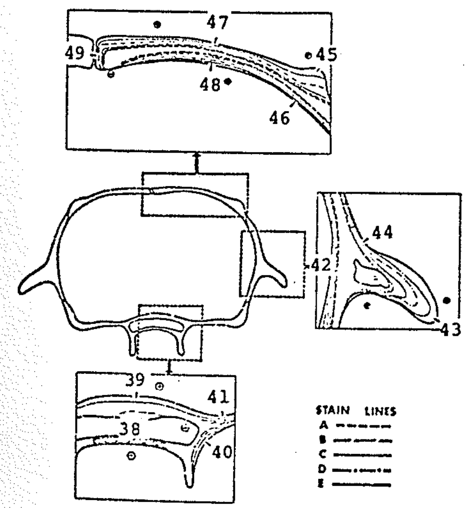
FIRST MOLAR REGION



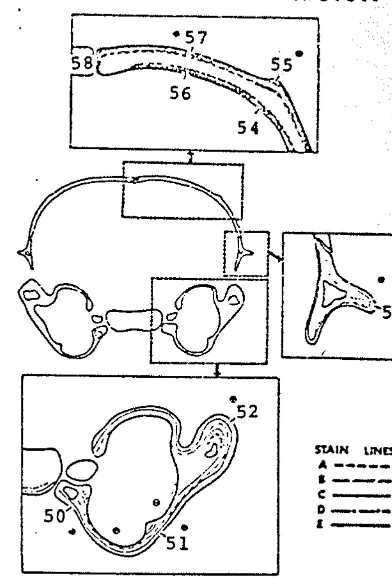
ZYGOMATIC REGION



SQUAMA TEMPORAL REGION



TYMPANIC BULLA REGION



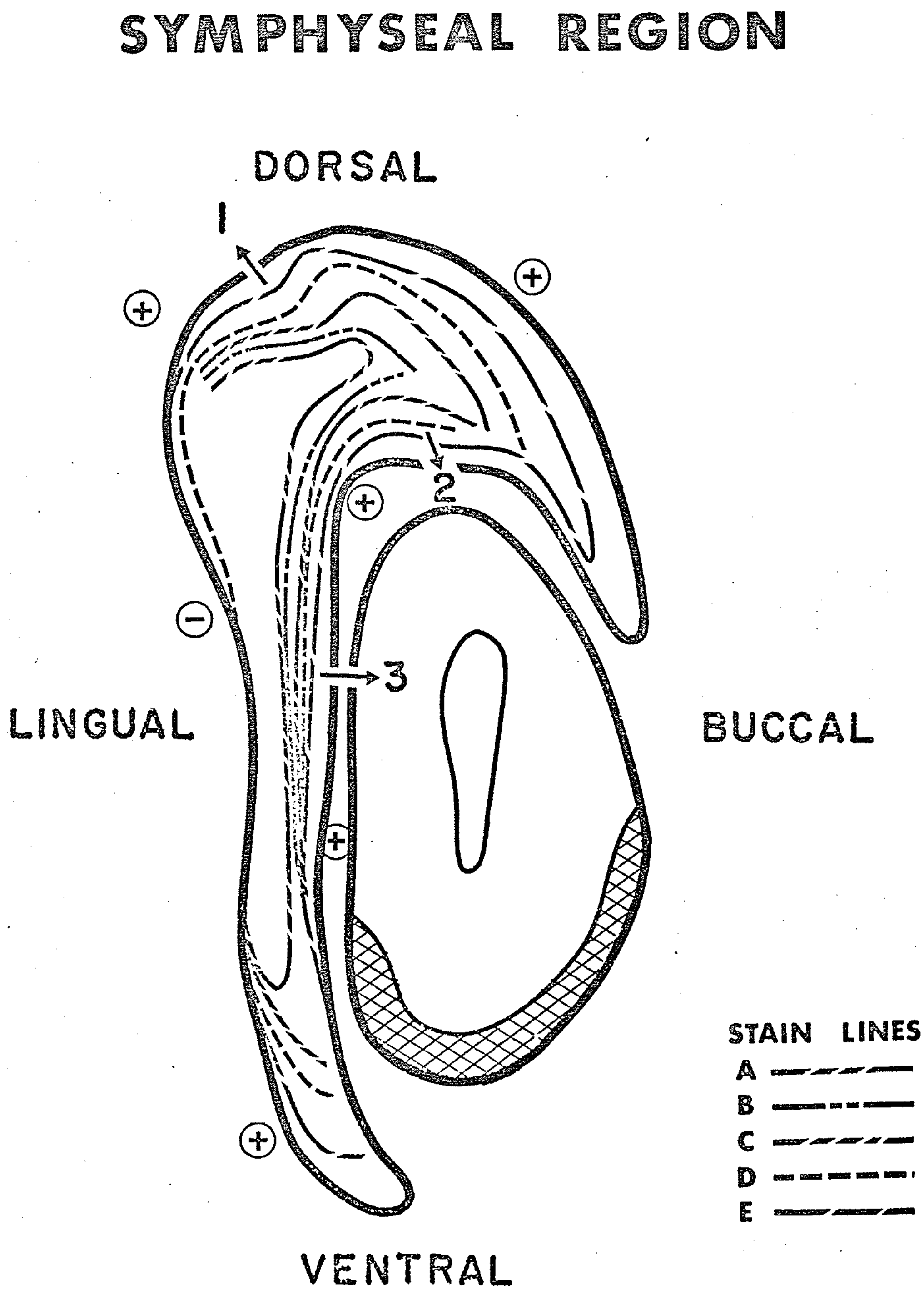


Figure 9. Stain Line Pattern and Site Locations in the Symphyseal Region of the Mandible.

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[1]Cranial diagrams were modified from Cleall et al. (1971).

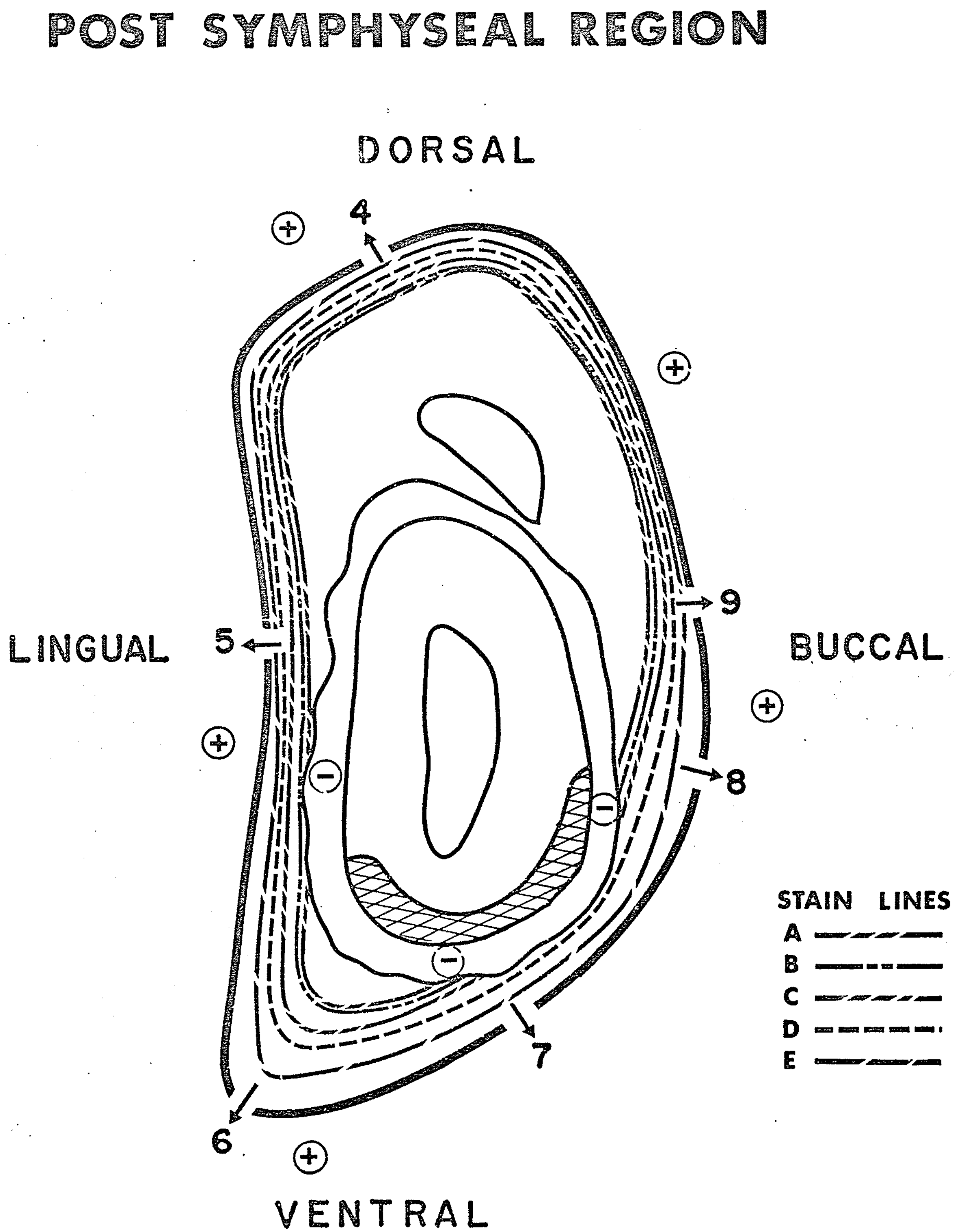


Figure 10. Stain Line Pattern and Site Locations in the Post Symphyseal Region of the Mandible.

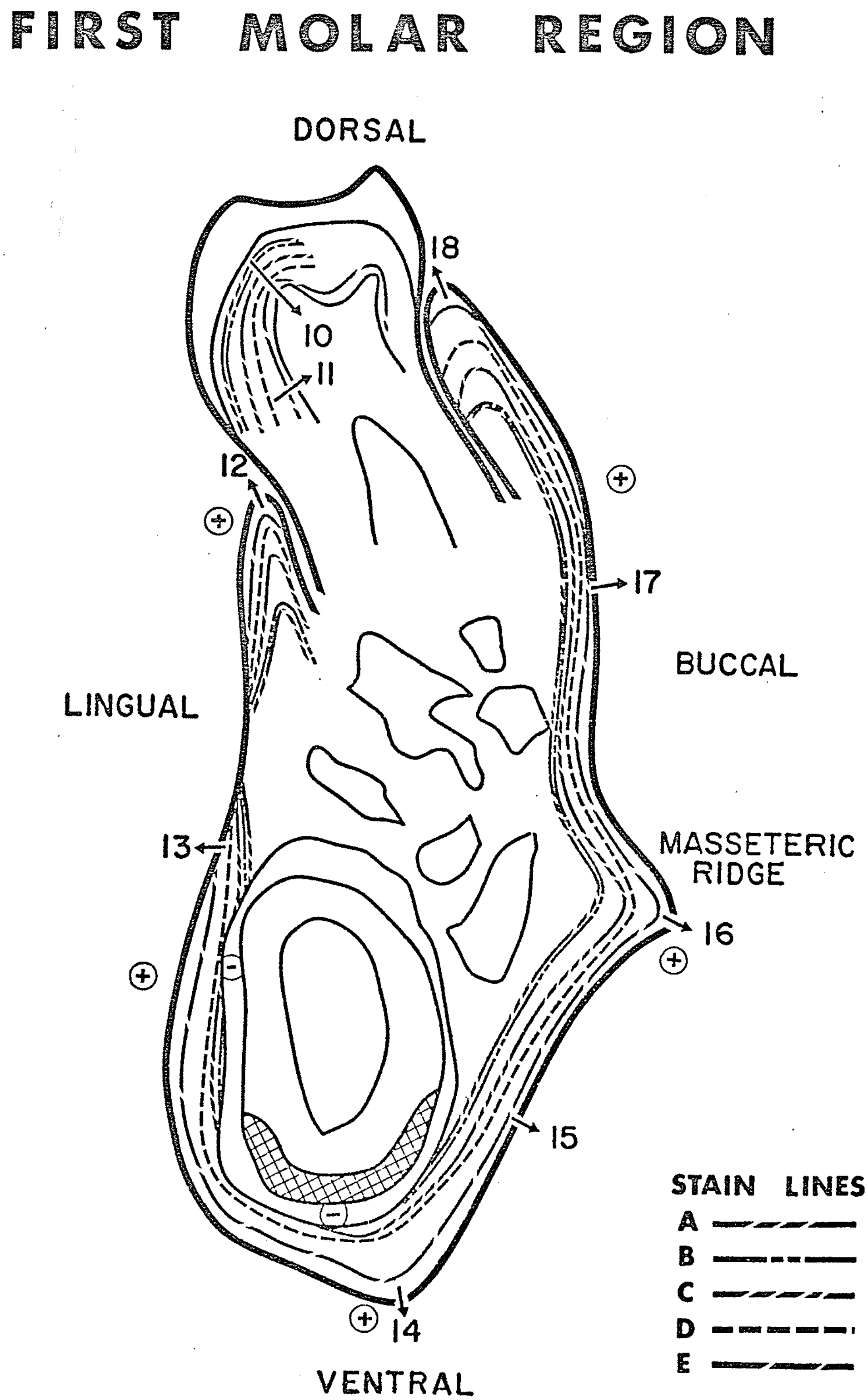


Figure 11. Stain Line Pattern and Site Locations in the First Molar Region of the Mandible.

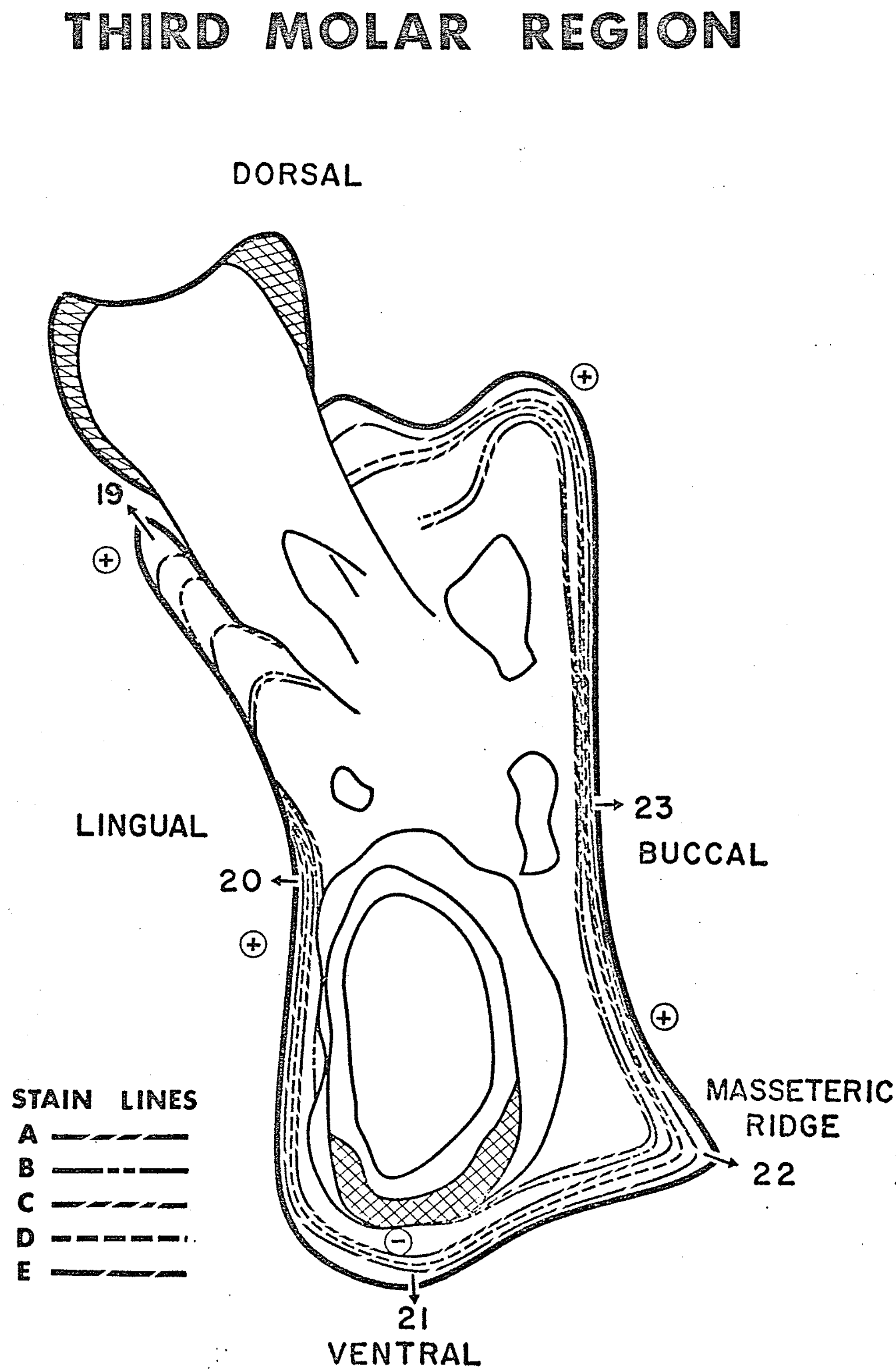


Figure 12. Stain Line Pattern and Site Locations in the Third Molar Region of the Mandible.

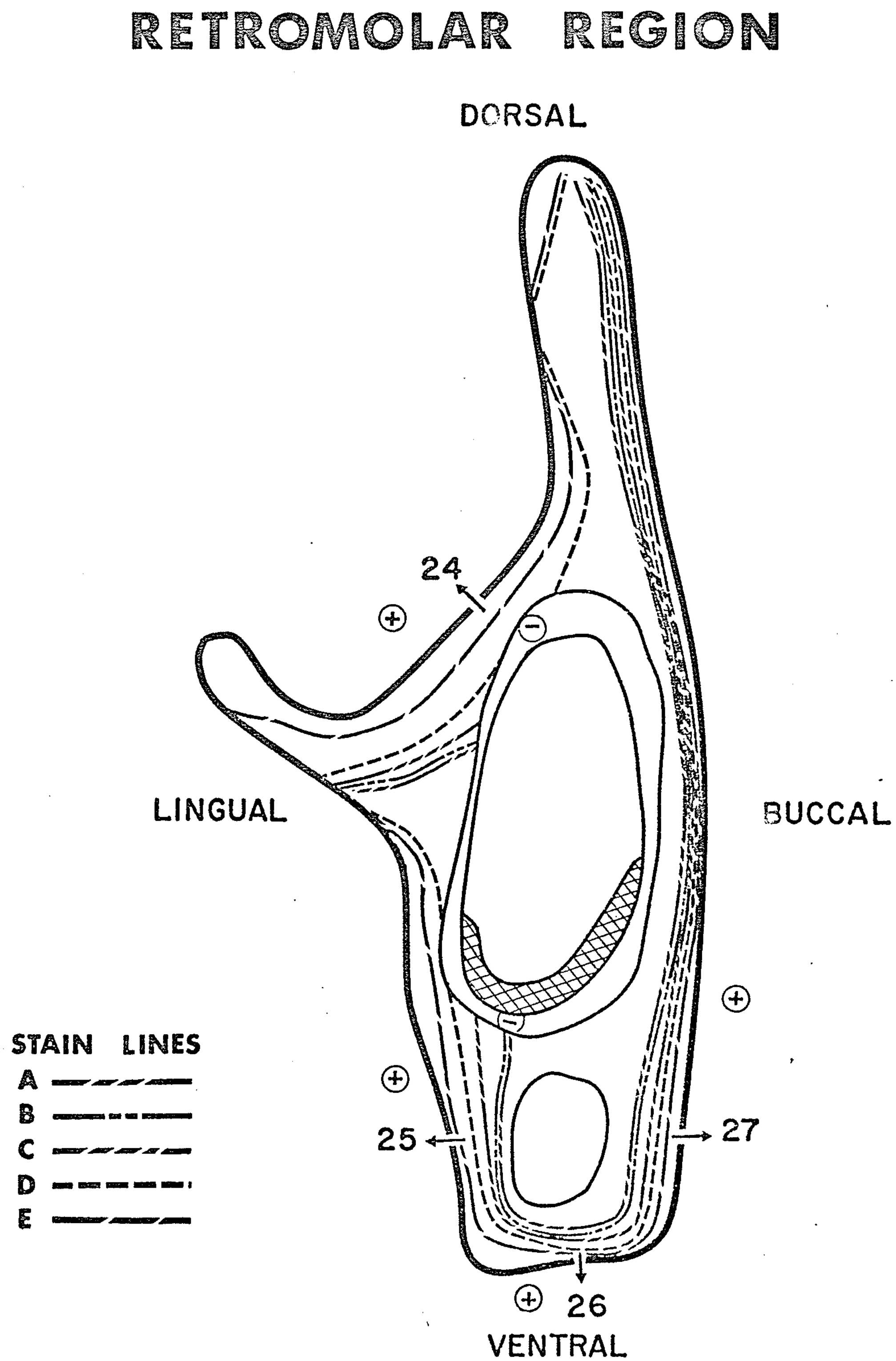


Figure 13. Stain Line Pattern and Site Locations in the Retromolar Region of the Mandible.

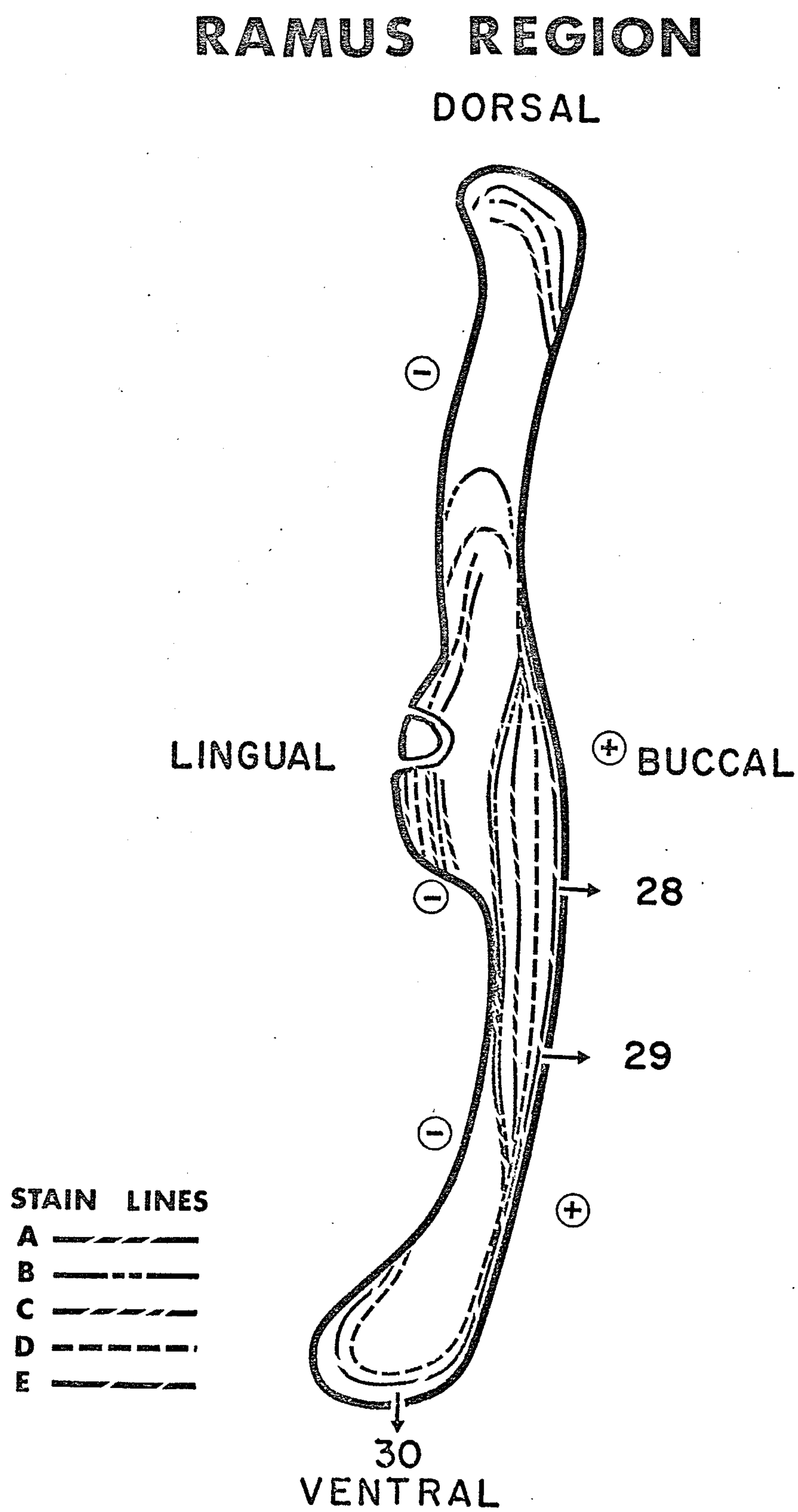


Figure 14. Stain Line Pattern and Site Locations in the Ramus Region of the Mandible.

INCISOR REGION

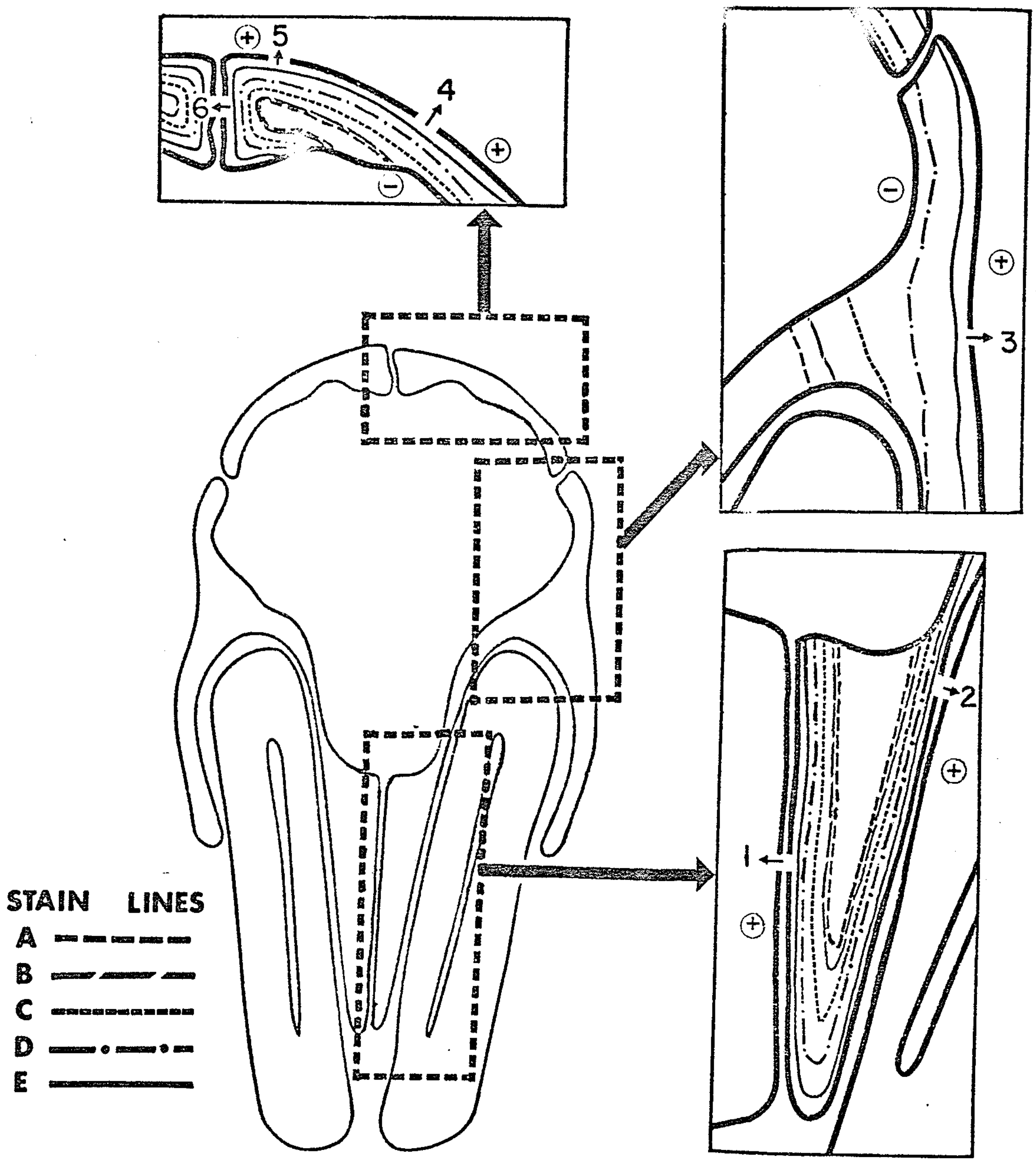


Figure 15. Stain Line Pattern and Site Locations in the Incisor Region of the Cranium.[1]

[1]Cranial diagrams were modified from Cleall et al. (1971).

PREMAXILLARY REGION

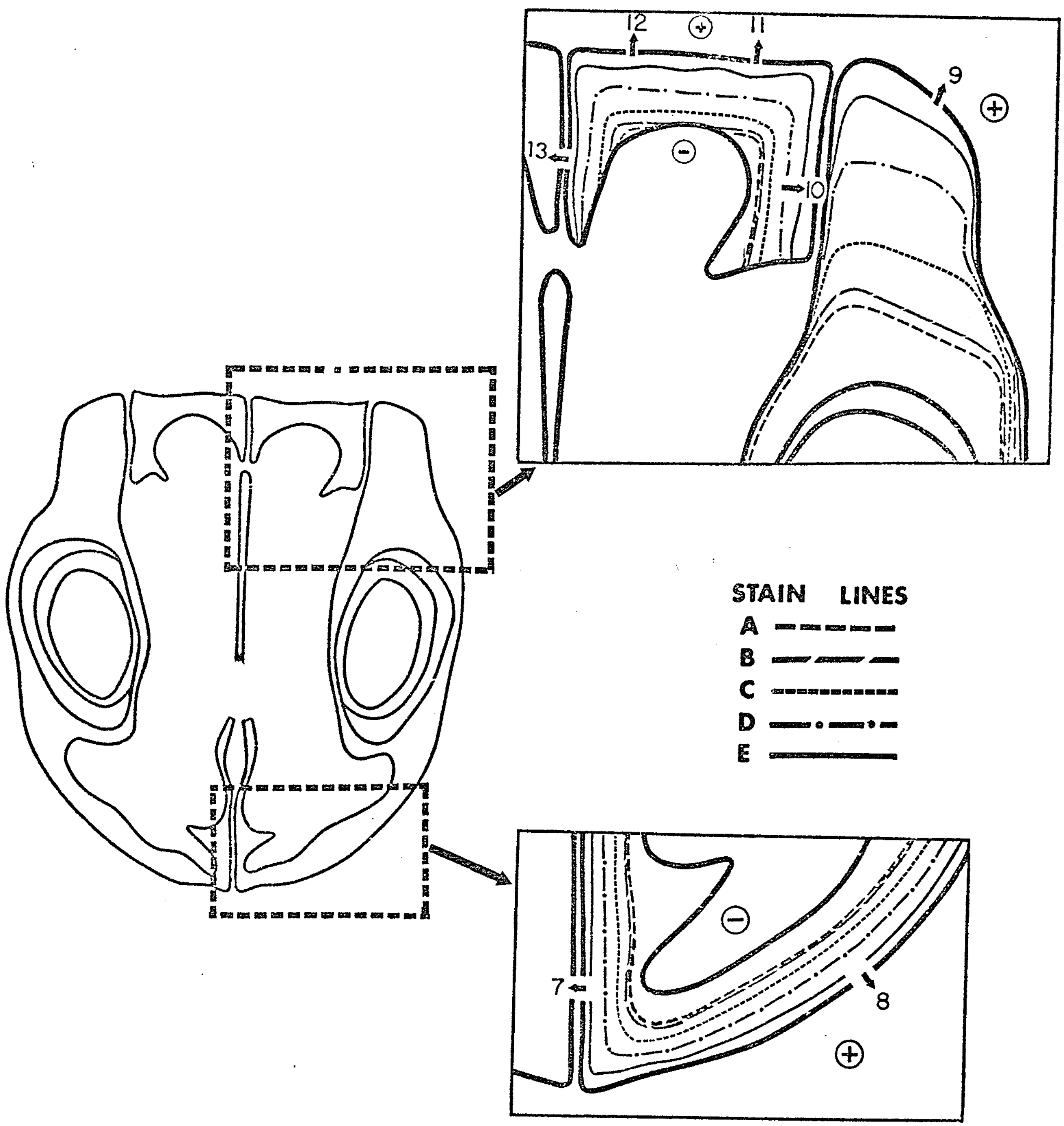


Figure 16. Stain Line Pattern and Site Locations in the Premaxillary Region of the Cranium.

MALAR PROCESS REGION

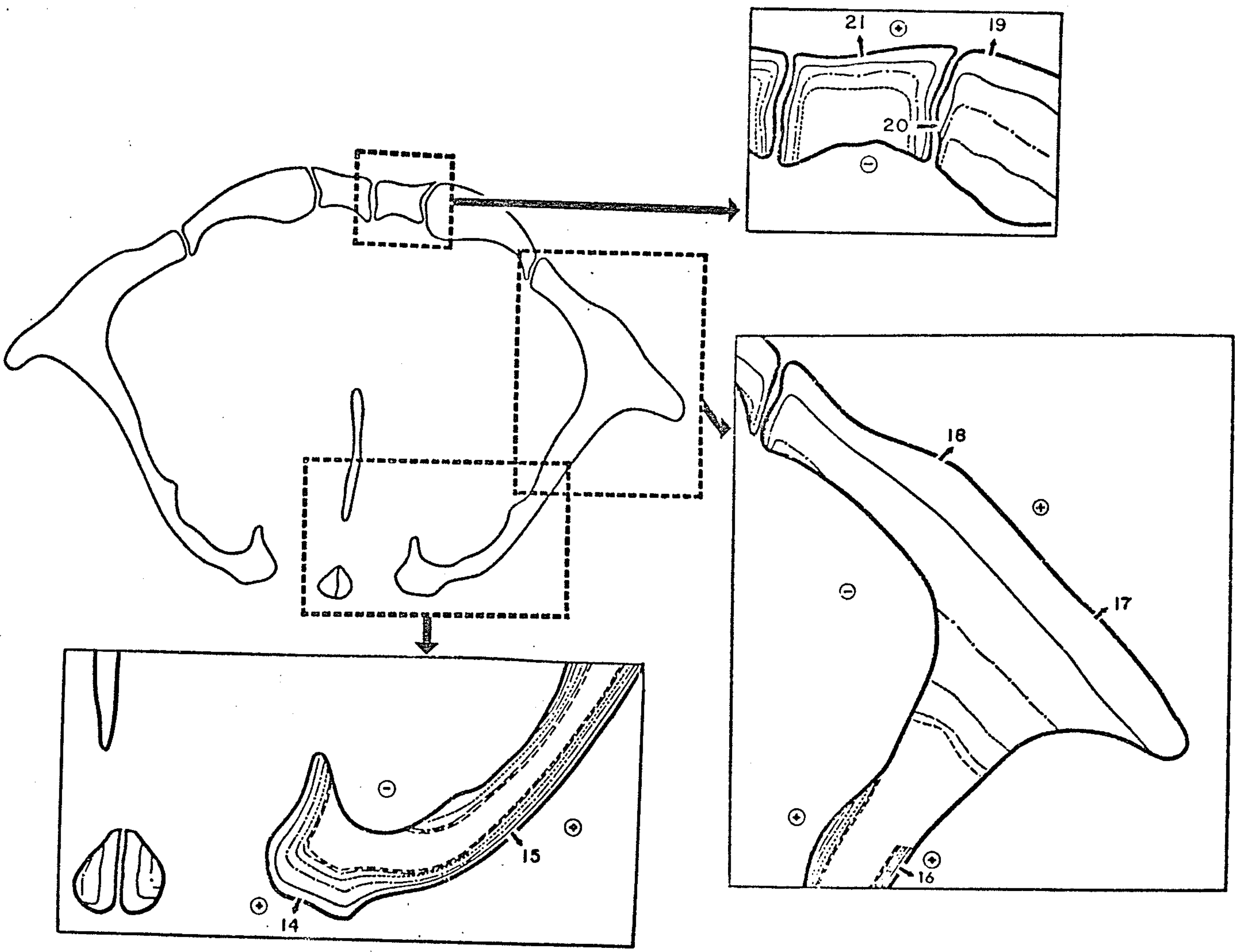


Figure 17. Stain Line Pattern and Site Locations in the Malar Process Region of the Cranium.

FIRST MOLAR REGION

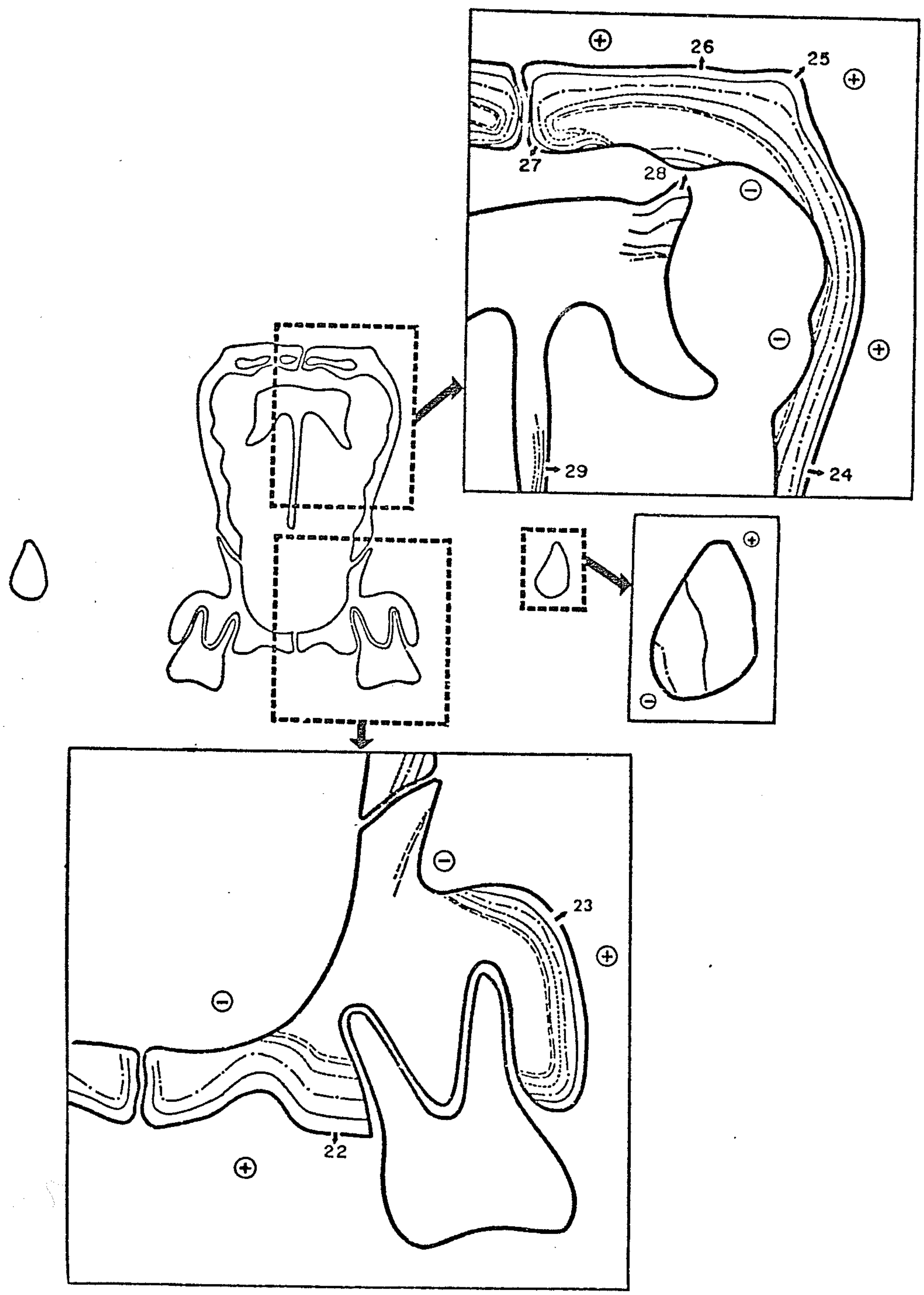


Figure 18. Stain Line Pattern and Site Locations in the First Molar Region of the Cranium.

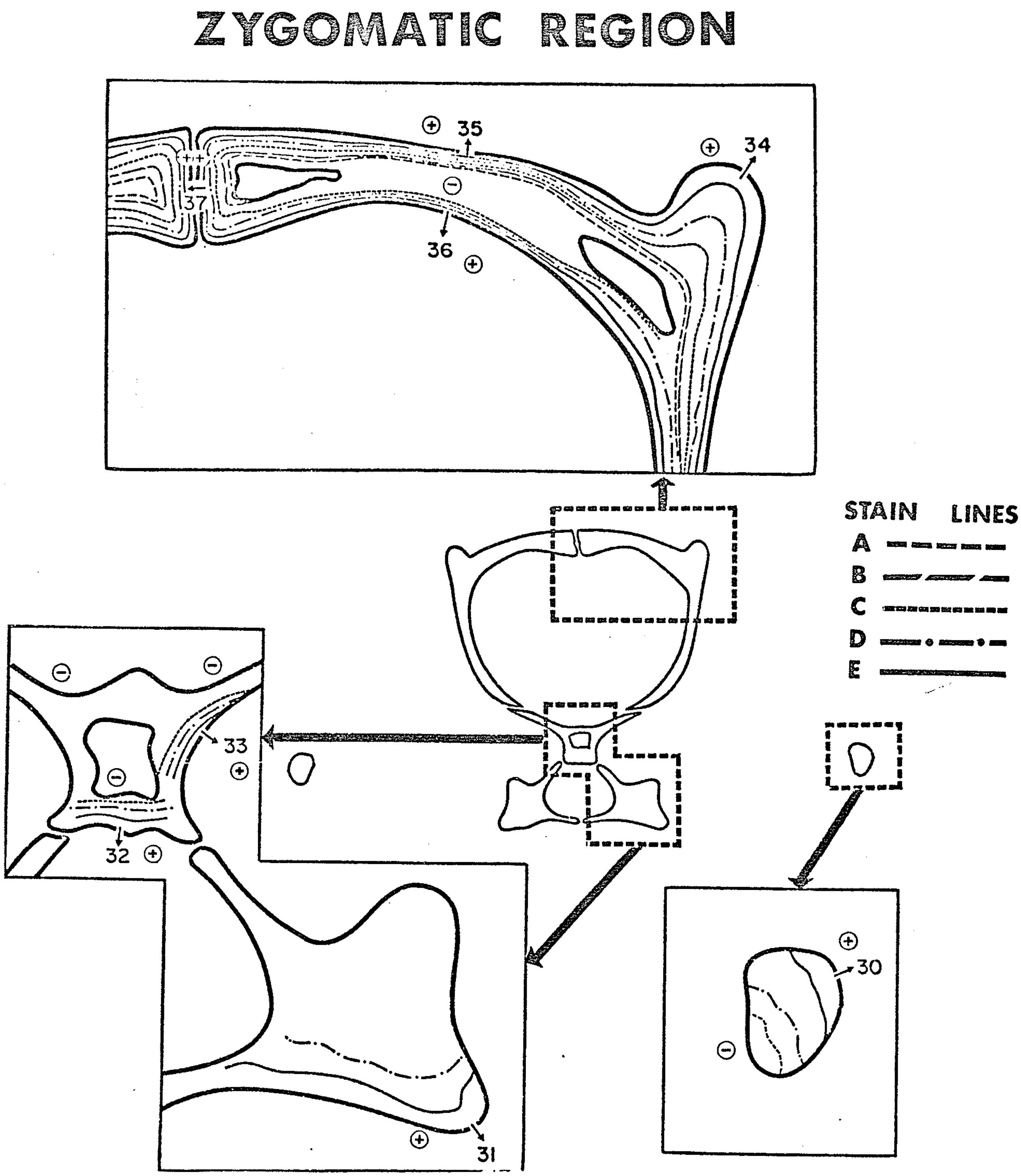


Figure 19. Stain Line Pattern and Site Locations in the Zygomatic Region of the Cranium.

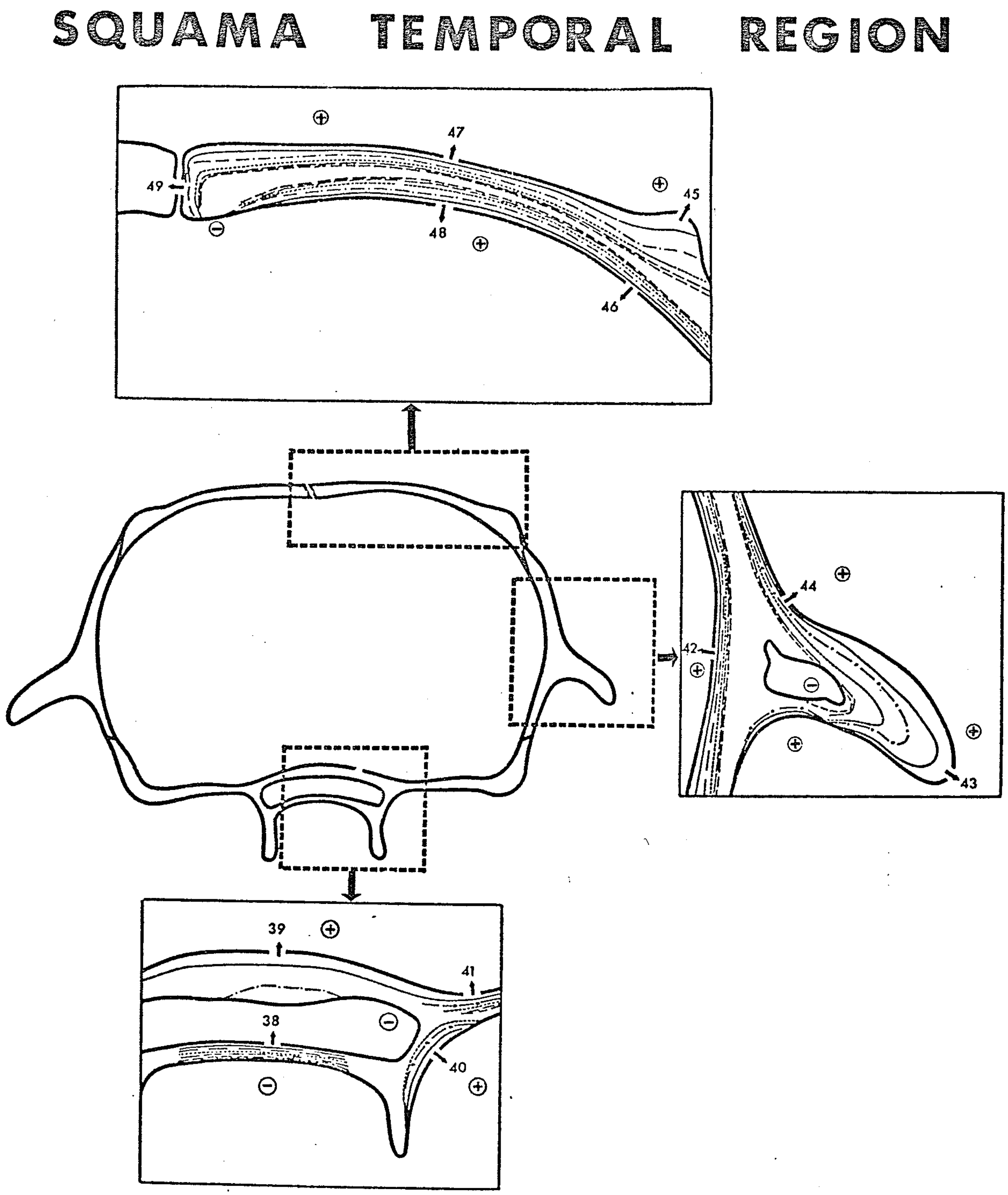


Figure 20. Stain Line Pattern and Site Locations in the Squama Temporal Region of the Cranium.

TYMPANIC BULLA REGION

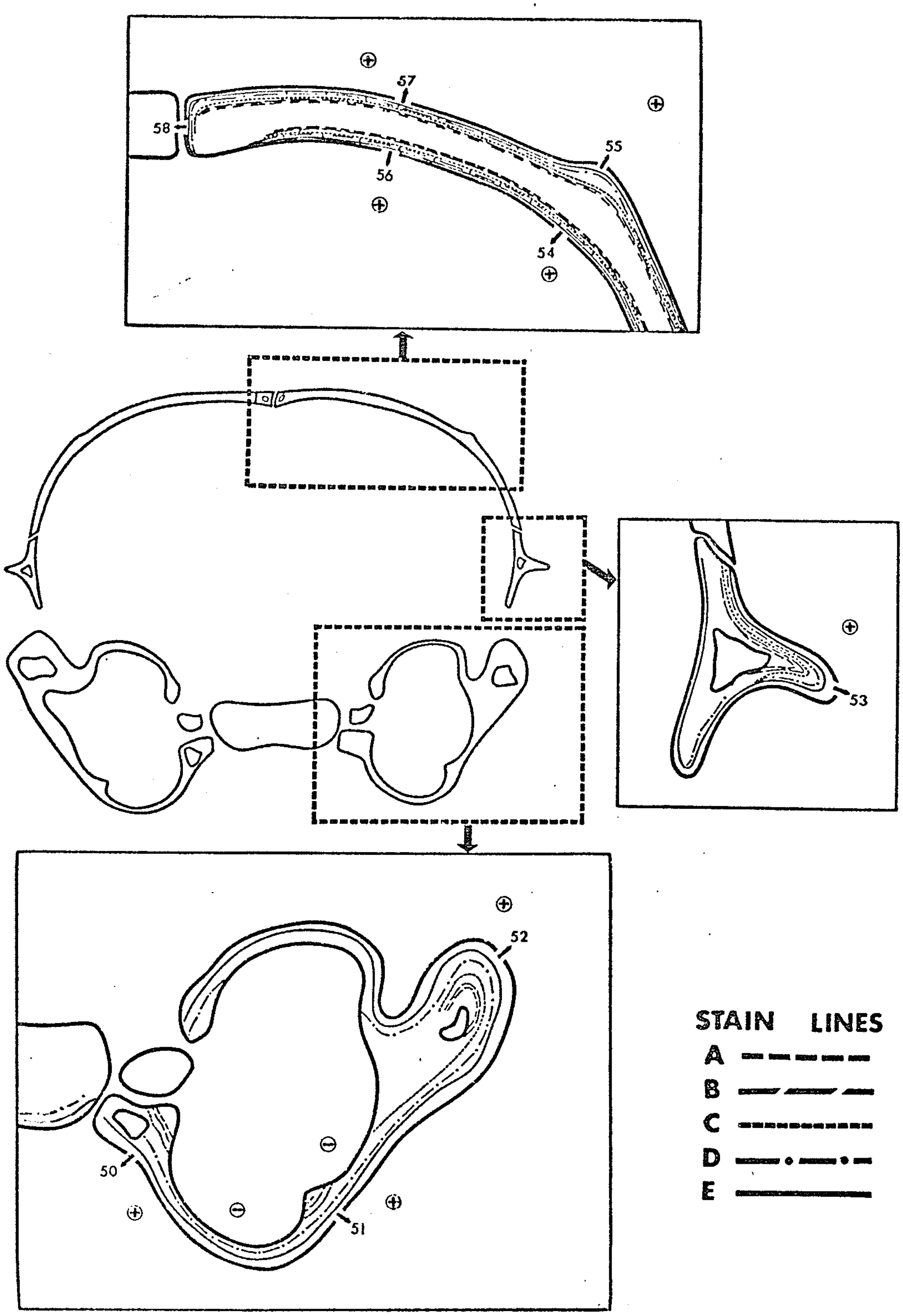


Figure 21. Stain Line Pattern and Site Locations in the Tympanic Bulba Region of the Cranium.

MANDIBLE
SUPERIOR BORDER

The superior aspect of the incisor process was a measurement site in both the Symphyseal Region and Post Symphyseal Region (Figs.9,10). As might be expected from a consideration of their anatomical relationship to the lower incisor, the growth rate of Site 1 was greater than that of Site 4 (Figs.22,23). The total amounts of bone apposition for the normal group were 360 microns and 260 microns, respectively. The usual normal growth curve was presented at Site 4. The plane of sectioning did not approximate the growth direction at Site 1 so the previously discussed artifact of a small contribution to the growth rate decrease in the EF interval was introduced. Mean increments of bone deposition are shown in Table IV.

The growth rate of the sham operation group was not significantly different from normal at either site; although the total growth was less than normal at Site 4 and more than normal at Site 1. The lesser growth rate of the operated side was not significant during any of the intervals.

The growth curve of the masseterectomy group reflected the usual pattern of alternative periods of rate increase and decrease at both sites. The operated side grew slower than the unoperated side and both sides showed

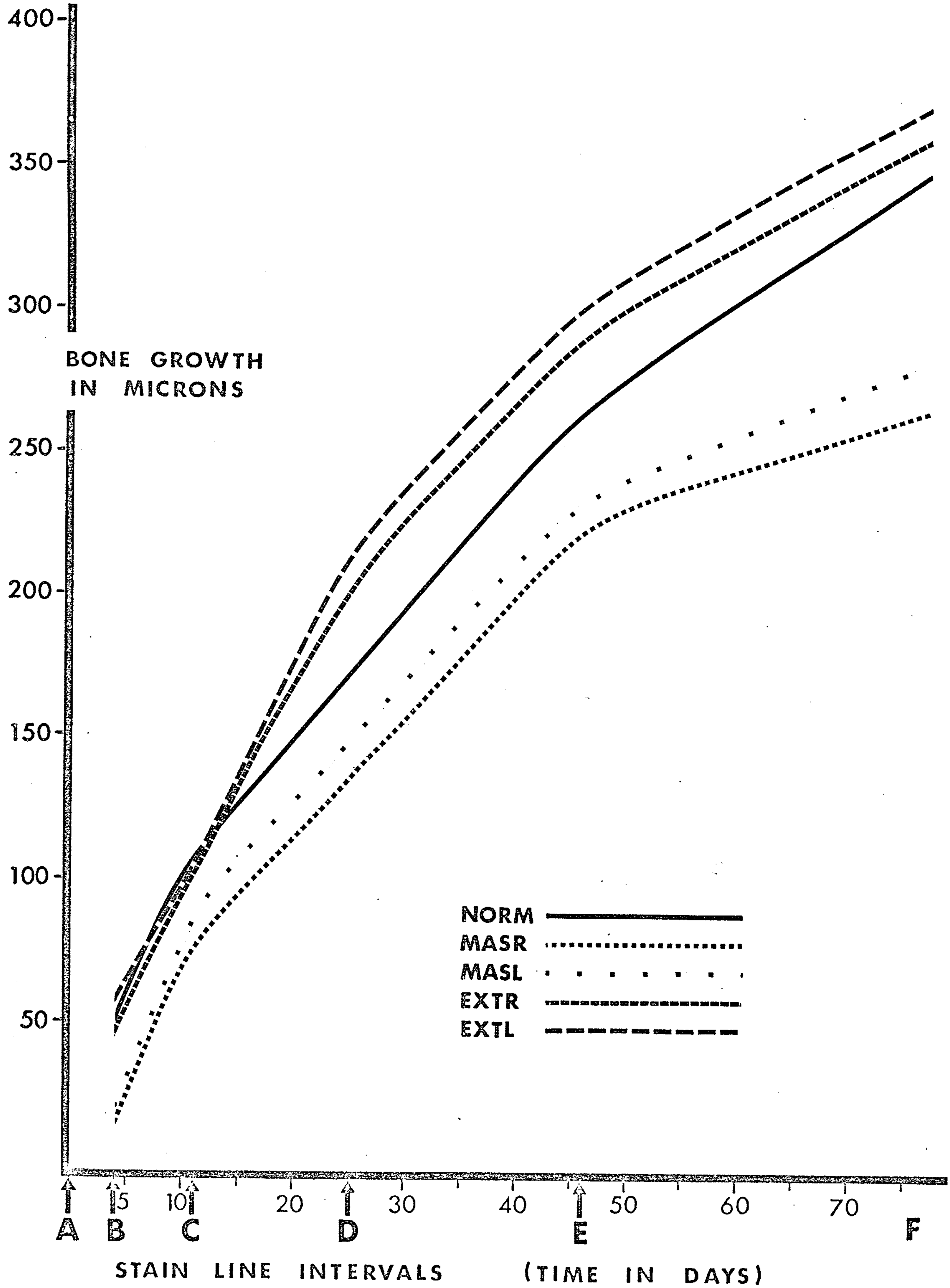


Figure 22. Cumulative Bone Apposition at Mandible Site 1.

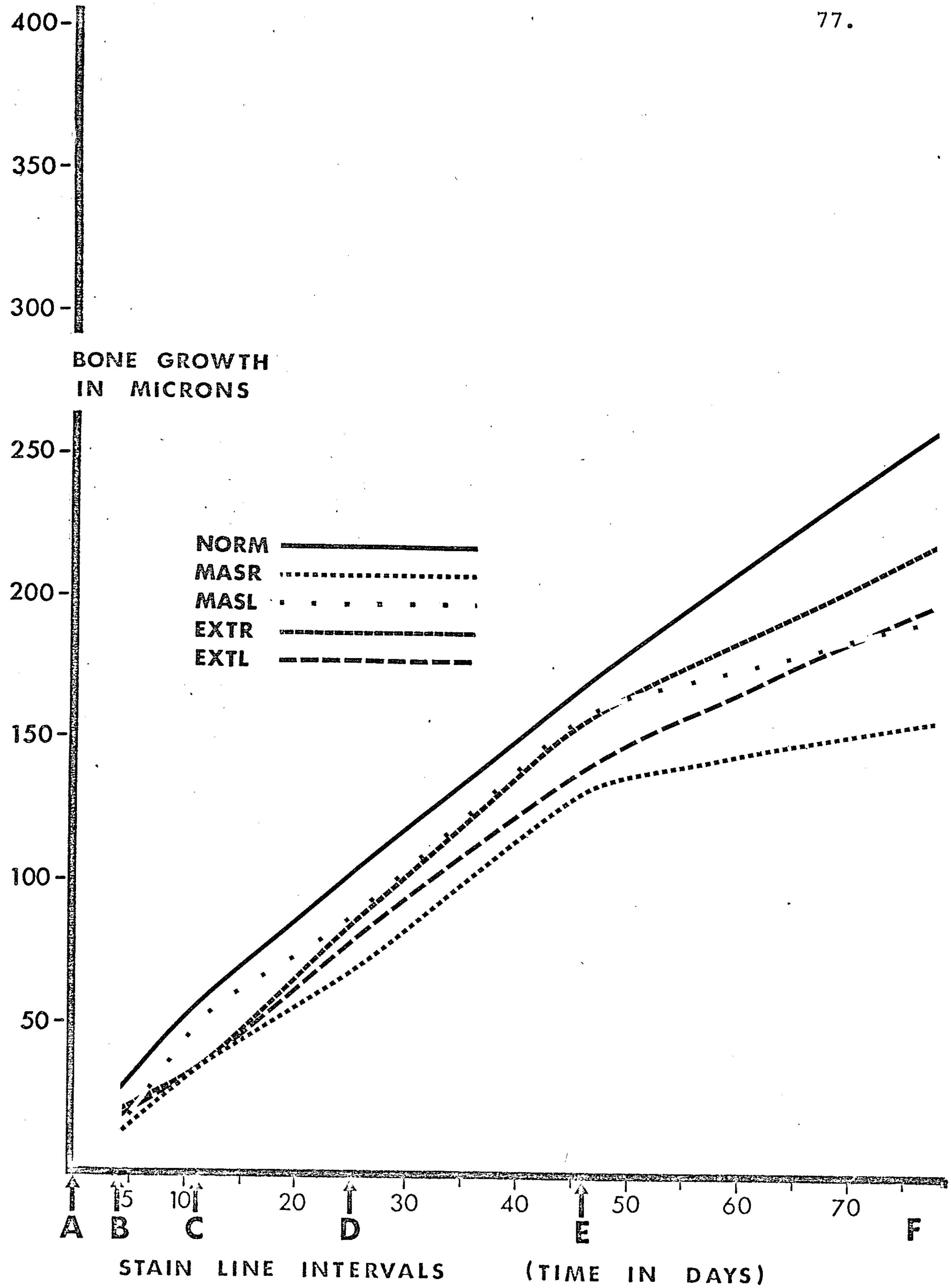


Figure 23. Cumulative Bone Apposition at Mandible Site 4.

TABLE IV

INCREMENTS OF BONE APPOSITION AT THE SUPERIOR BORDER

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					MANDIBLE SITE 1						
NORM	54	3	63	9	62	11	89	12	92	10	360
MASR	19	2	67	13	56	6	93	9	37	5	272
MASL	21	4	74	14	61	7	88	18	43	6	287
SHAR	46	5	49	5	80	12	96	14	86	15	357
SHAL	47	6	53	3	88	16	119	22	68	11	375
EXTR	49	11	63	10	103	16	90	12	60	9	365
EXTL	61	11	49	7	117	16	88	12	63	9	378
					MANDIBLE SITE 4						
NORM	31	1	33	3	45	3	69	3	81	9	259
MASR	14	2	23	4	36	3	67	6	21	2	161
MASL	16	2	40	5	35	4	76	7	30	8	197
SHAR	27	2	25	2	40	8	68	10	67	5	227
SHAL	28	1	42	12	47	6	62	9	58	5	237
EXTR	22	2	14	3	54	5	75	5	54	6	219
EXTL	19	2	18	3	47	4	65	5	50	6	199

a reduced total growth. At Site 4 the operated side did not show the customary growth acceleration in the BC interval and grew significantly slower ($P < .01$) than the unoperated side. The similarity of further increments (between sides) resulted in a total growth difference between sides that just reached significance at the $P = 0.5$ level.

In contrast to the masseterectomy group, the extraction group demonstrated a different response at each site. At Site 1 a significant difference ($P < .05$) between sides was noted in the BC interval with the operated side growing faster than the unoperated side to compensate for an initial retardation. Total apposition was equal between sides by the third stain injection. In the following CD interval, both sides grew faster than normal (EXTR $P = .05$, EXTL $P = .01$) thereby ensuring a total amount of bone deposition slightly above normal value.

At Site 4 a more usual pattern for the extraction group curves was observed. Both AB and BC intervals had slower growth than normal with the BC daily increment being less than the AB in accordance with the feature of a delayed growth slowdown. These rates were significantly different from normal at $P = .01$ for both intervals. During the CD interval the extraction group grew fastest; the right side rate was significantly different from the slowest group rate, the masseterectomy rate, at $P = .05$. A period of rate decline followed in the EF interval which was less than normal ($P < .01$) and was the usual finding in the extraction group pattern.

The nature of group interactions were such that no significant differences were recorded for the AE interval at either Site 1 or 4. This demonstrated the tendency to maintain normal amounts of bone apposition and the "catch up" abilities of the experimental groups. However, the rapid decrease in growth rate during the last interval (EF) that is customary with the masseterectomy group resulted in significantly less total growth than that of the majority of the other groups.

INCISOR SOCKET

Comparison of bone apposition rates at the superior (Site 2) and lingual (Site 3) margin of the incisor socket in the Symphyseal Region, demonstrated the coordinated reactions to unilateral functional disturbance shown by the operated and unoperated sides in different locations. On the superior aspect of the socket, the operated sides were all growing slower than the unoperated sides; while on the lingual margin the reverse was true (Table V).

The total amount of normal growth was approximately 2½ times greater on the superior aspect, but the most marked inter-site difference was that of the unoperated side of the extraction group (Figure 24). The growth rates at these two sites give an indication of the direction and speed of drift of the lower incisors. Individual group comparisons showed numerous statistically significant differences.

<u>Sham Group</u>. Both sides of the sham group had the same growth trend at Site 2; that was notable for a decreased rate during the AB interval ($P = .05$), which become more significantly decreased ($P = .01$) during the BC interval (Figure 24). Thereafter, the growth increments approximated the normal values. In contrast at Site 3, the right side of the sham group had a curve that demonstrated no significant variation from normal, but did have a "catch up" phase

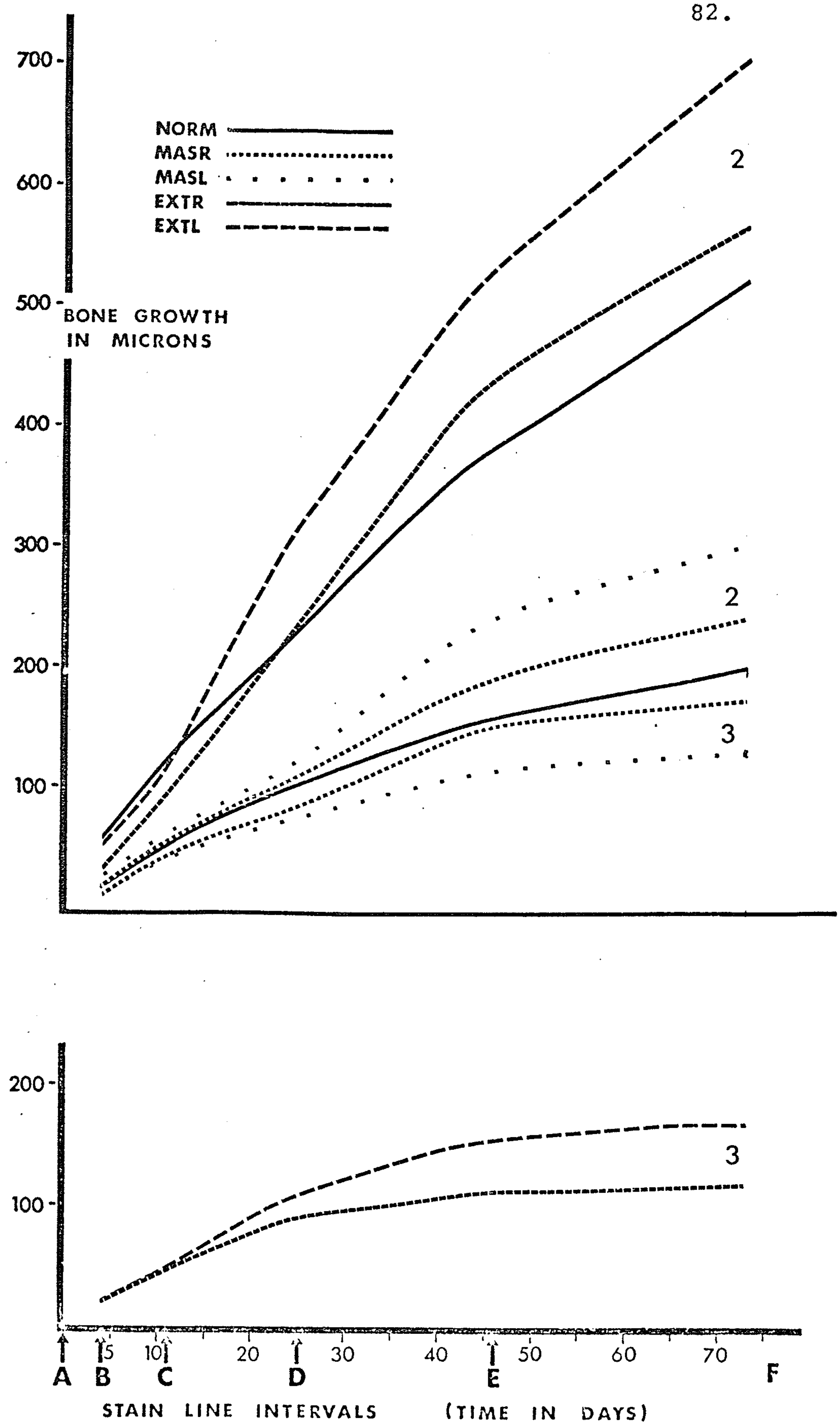


Figure 24. Cumulative Bone Apposition at Mandible Sites 2 and 3.

TABLE V.

INCREMENTS OF BONE APPOSITION AT THE INCISOR SOCKET

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					MANDIBLE SITE 2						
NORM	63	4	69	7	100	17	154	14	148	9	534
MASR	31	7	28	6	50	9	87	9	47	12	243
MASL	28	6	38	4	56	7	127	16	57	10	306
SHAR	41	8	44	6	87	11	151	20	151	27	474
SHAL	46	9	39	5	90	13	151	24	163	30	489
EXTR	36	3	58	8	138	13	213	16	121	24	566
EXTL	53	7	62	6	202	23	213	26	173	20	703
					MANDIBLE SITE 3						
NORM	24	1	38	3	43	3	59	6	45	7	209
MASR	14	2	37	6	35	4	69	9	23	6	178
MASL	16	2	30	5	31	4	41	7	16	6	134
SHAR	21	2	30	3	52	7	54	5	33	12	190
SHAL	21	3	26	3	38	4	51	6	11	4	147
EXTR	21	2	26	3	61	7	49	11	14	5	171
EXTL	19	2	28	4	43	6	23	10	6	4	119

during interval CD when the rate was more than normal. The left side grew slower than normal during the BC interval ($P = .05$) and this growth discrepancy was again evident, to a more marked degree, in the EF interval ($P = .01$). The differences between sides were significant at $P < .05$ during the CD and EF intervals.

Masseterectomy Group. A discrepancy between sides was also evident in the masseterectomy group rates for Site 3, and occurred during the DE interval ($P < .01$) as a decline in growth of the unoperated side. This rate reduction was sufficiently large to make the overall growth of the left side significantly smaller ($P < .05$). The operated side curve traced the customary pattern of the masseterectomy group with only rate decreases during the AB and EF intervals being significant. The unoperated side curve differed from the pattern by a lack of acceleration during the DE interval and a more marked acceleration during the EF interval ($P = .01$).

At Site 2, the greatest difference in growth increments between sides for the masseterectomy group was noted during the DE interval ($P < .05$). Growth of the left side was not significantly less than normal for this interval only. The right side grew significantly less than normal throughout the experimental period.

Extraction Group. The extraction group had the largest total growth difference between sides at both Site 2 and Site 3. The curve of growth at Site 2 behaved opposite to the findings of the masseterectomy group reaction in that a greater than normal rate was recorded during the CD, DE and EF intervals for the unoperated side. The significance of this difference decreased from P = .01 to P = .05 to not significant. The right side grew slower than the left and was only significantly faster than normal during the DE interval (P = .05).

There was a similarity of growth pattern between the extraction and masseterectomy groups at Site 3. However, after a mutual initial retardation the extraction group rates accelerated in the CD interval so that the right side was significantly faster than normal (P = .01). These followed at late deceleration in the EF interval that was shared by the left side (P = .01), but the left side had also been subject to a rate decline in the DE interval (P = .01). These differences in the timing of the deceleration phase resulted in the right side showing more total bone apposition than the left side (P = .05).

The means and standard errors of increments of bone apposition at these sites are shown in Table V.

LINGUAL SURFACE

Normal Growth. Measurement sites on the lingual surface were located, one each, in the following mandibular cross-sections: Post Symphyseal Region (Site 5), First Molar Region (Site 13), Third Molar Region (Site 20), and the Retromolar Region (Site 25). The amount of normal growth increased gradually (in accordance with increasing thickness of the mandibular body) from anterior to posterior along the lingual surface. In the Retromolar Region (Site 25) a dramatic 2½ fold increase over apposition at Site 5 occurred which was necessary to convert the thin angular process into the body of the mandible during the process of area relocation.

A finding common to all four sites was the greater amount of total growth of the normal group which was significantly more than that of the extraction and masseterectomy groups. The sham group registered its greatest retardation at Site 5 (Figure 25).

Experimental Patterns

The patterns of reaction illustrated by the growth curves of the experimental groups were similar for Sites 5, 13 and 20. The amounts of bone apposition, however, varied in accordance with the anteroposterior location of the site as noted for normal growth. Site 20 demonstrates the main features of these reaction patterns (Figure 28).

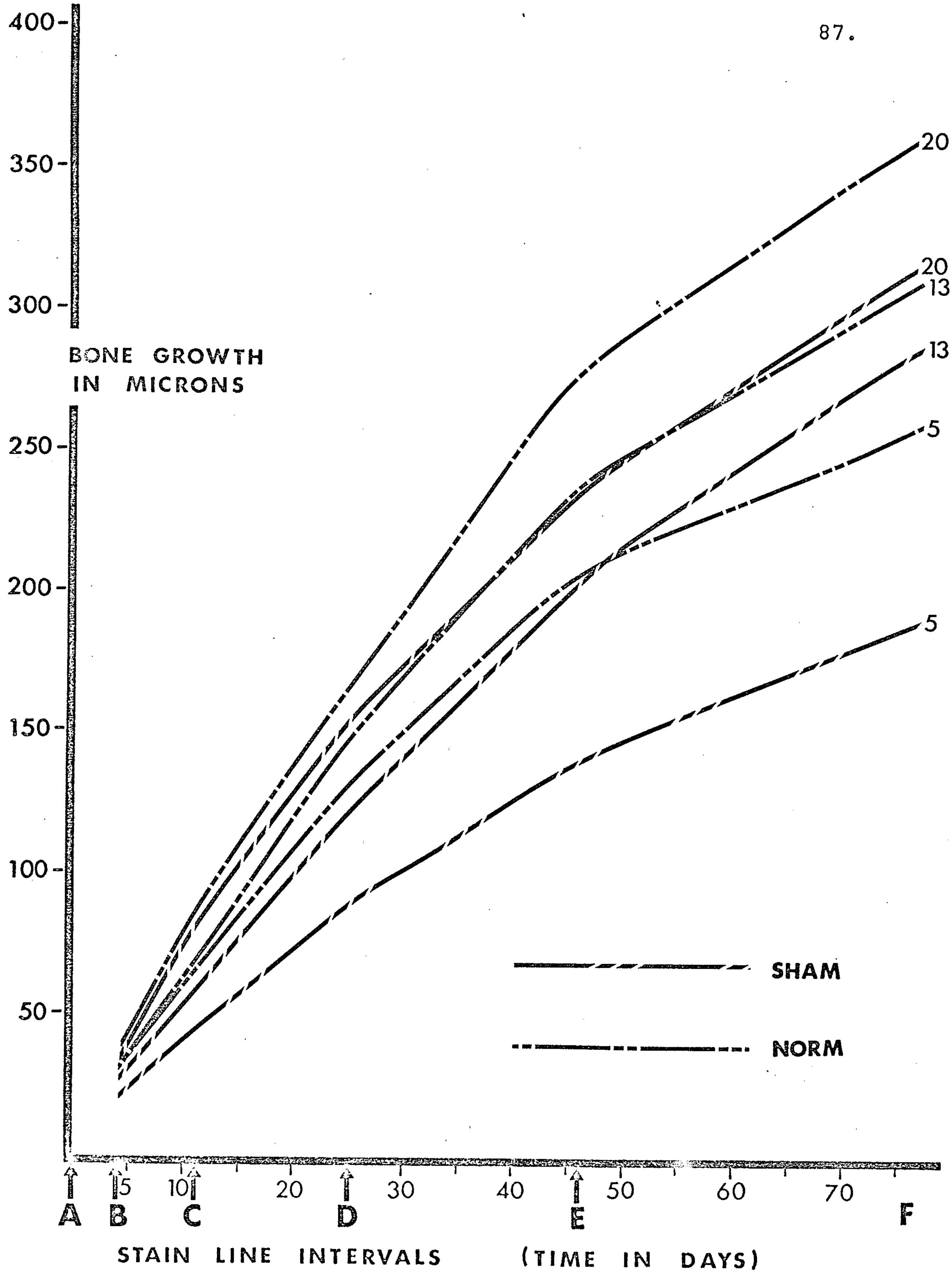


Figure 25. Cumulative Bone Apposition of Sham Group at Mandible Sites 5, 13 and 20.

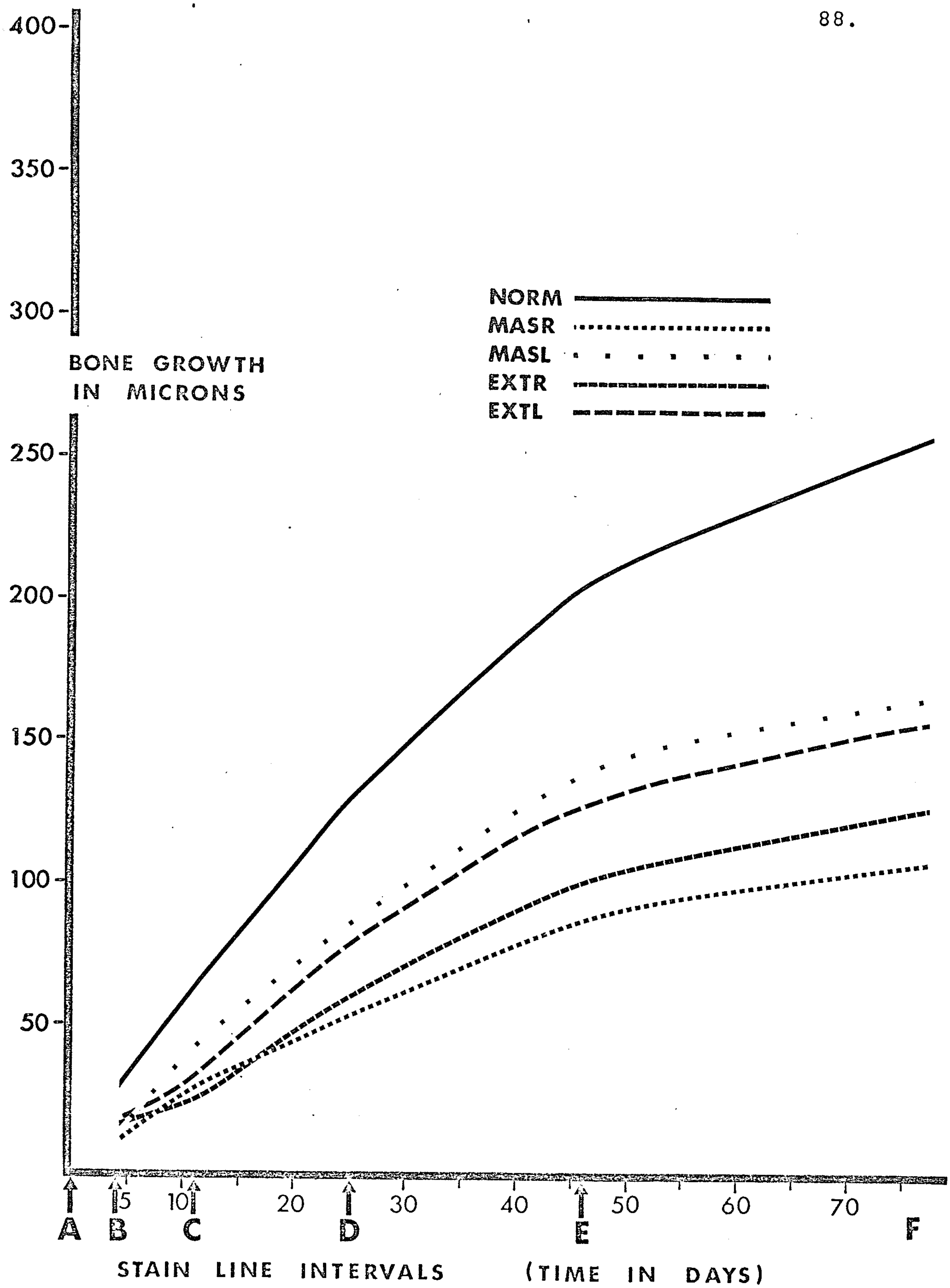


Figure 26. Cumulative Bone Apposition at Mandible Site 5.

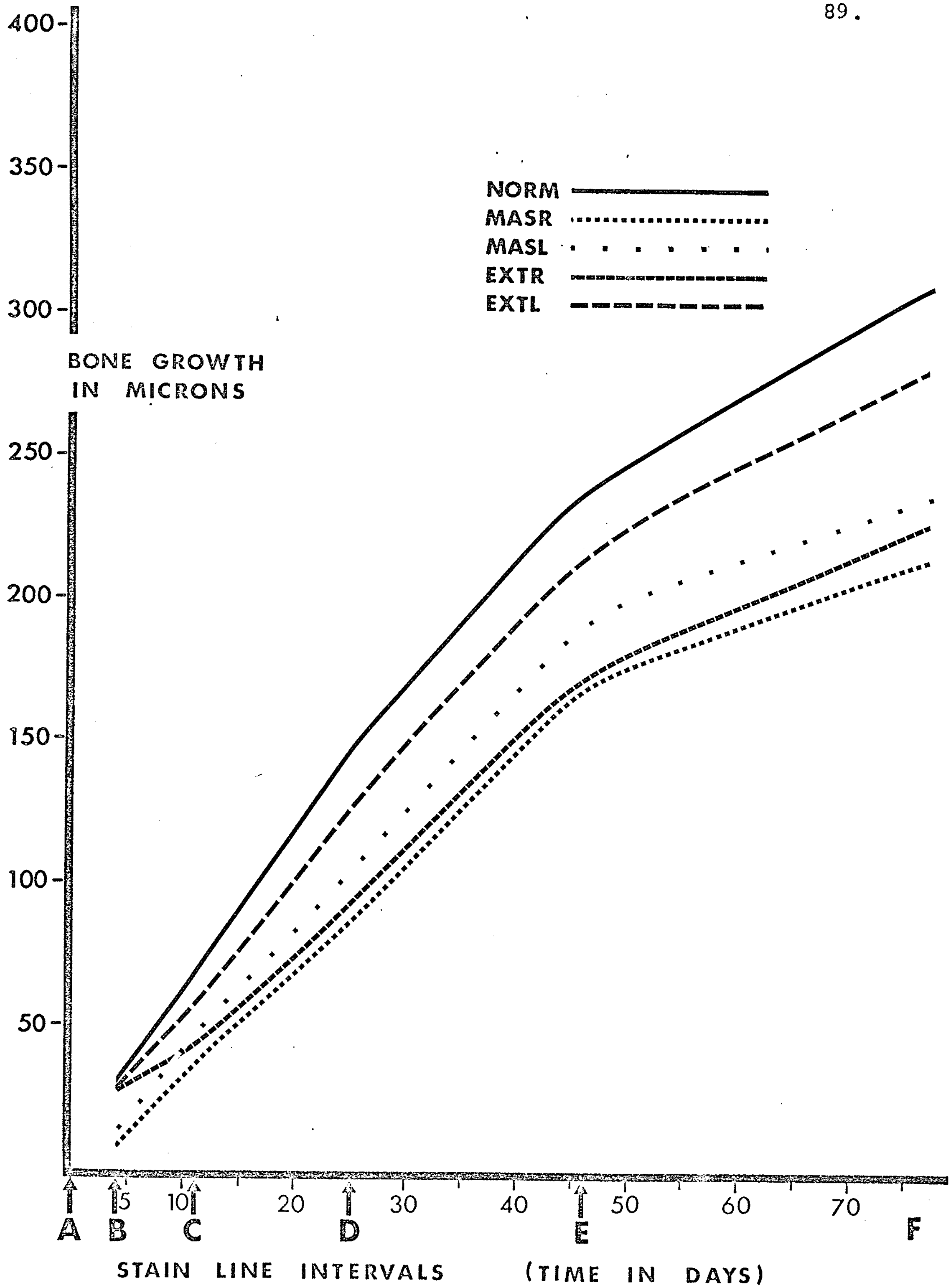


Figure 27. Cumulative Bone Apposition at Mandible Site 13.

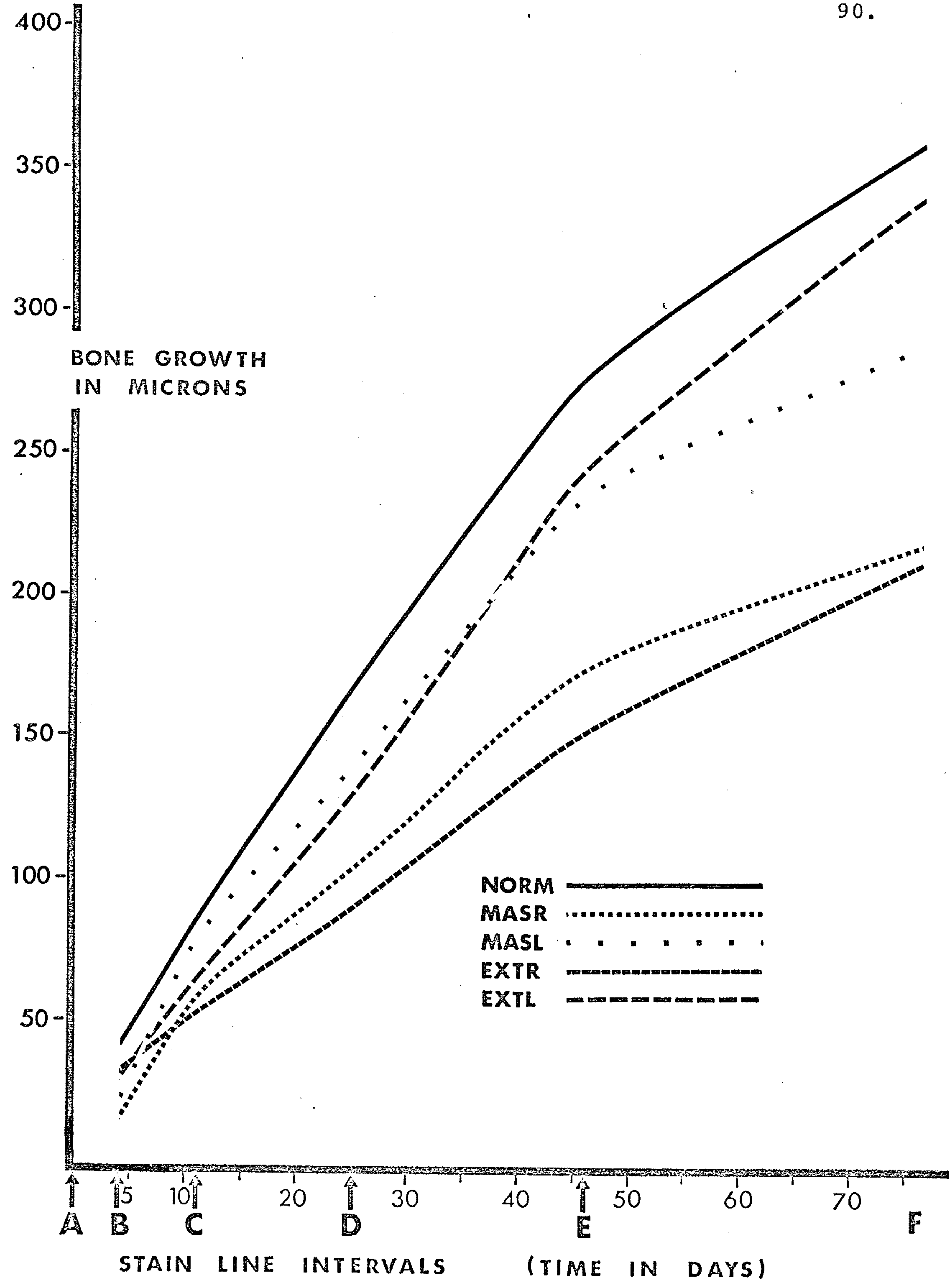


Figure 28. Cumulative Bone Apposition at Mandible Site 20.

TABLE VI

INCREMENTS OF BONE APPOSITION AT THE LINGUAL SURFACE

MEANS AND STANDARD ERRORS IN MICRONS

	AB		BC		CD		DE		EF		
GROUP	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	TOTAL
					MANDIBLE SITE 5						
NORM	31	1	36	2	69	4	79	4	45	4	260
MASR	11	1	20	4	27	6	34	5	19	3	111
MASL	15	2	30	4	45	4	58	7	21	6	169
SHAR	19	1	23	2	44	6	59	9	48	9	193
SHAL	23	3	27	4	47	4	48	6	42	9	187
EXTR	17	2	8	2	39	6	42	6	22	7	128
EXTL	16	2	19	3	48	5	52	5	24	7	159
					MANDIBLE SITE 13						
NORM	31	1	39	3	83	5	93	5	66	5	312
MASR	9	1	29	2	51	4	88	5	40	10	217
MASL	14	1	35	4	59	5	93	7	38	10	239
SHAR	30	2	32	2	69	6	89	9	81	6	301
SHAL	27	2	34	4	61	6	81	7	72	9	275
EXTR	28	2	17	3	52	2	84	4	47	3	228
EXTL	29	2	31	3	72	7	92	13	59	7	283
					MANDIBLE SITE 20						
NORM	39	1	50	3	82	4	114	7	74	5	359
MASR	16	1	45	4	47	5	73	9	37	11	218
MASL	22	3	60	6	60	4	100	6	46	10	288
SHAR	41	4	46	5	76	10	84	8	72	10	319
SHAL	34	2	48	5	73	6	79	10	72	9	306
EXTR	34	2	21	4	36	4	66	9	53	7	210
EXTL	32	2	35	2	65	7	120	12	47	6	299
					MANDIBLE SITE 25						
NORM	82	6	118	9	171	15	133	15	146	19	650
MASR	36	4	75	9	113	12	163	17	61	7	448
MASL	37	6	91	16	99	15	164	22	71	11	462
SHAR	42	6	95	21	158	24	119	16	128	16	542
SHAL	51	5	85	16	151	19	123	19	141	19	551
EXTR	48	6	37	6	111	13	115	11	86	13	387
EXTL	48	8	39	4	115	12	86	7	55	7	343

In each instance the curves of the operated sides of the masseterectomy and extraction groups showed the slowest rate of apposition (P = .01), and there were no significant differences between these two sides after the second interval (BC). The latter finding also applied when the unoperated sides of the extraction and masseterectomy groups were compared. The varying initial responses of these two groups (a marked initial rate decrease in the masseterectomy group and a delayed decrease in the extraction rate) accounted for their differences during the AB and BC intervals (P = .01). Such comparative behavior of the growth curves was a finding common to many of the sites investigated.

The differences between left and right sides were highly significant ($P < .01$) for both the extraction and masseterectomy groups, but the sham group demonstrated no great discrepancies between sides. The side differences are an expression of the coordinated remodelling activity that influenced the observations reported for Sites 2 and 3, as well as those of the lingual surface rates. The nature of these remodelling changes will be a topic pursued in the discussion.

The growth curve pattern for Site 25, the lingual surface in the Retromolar Region, did not share the common features of the other lingual sites, rather it was a good

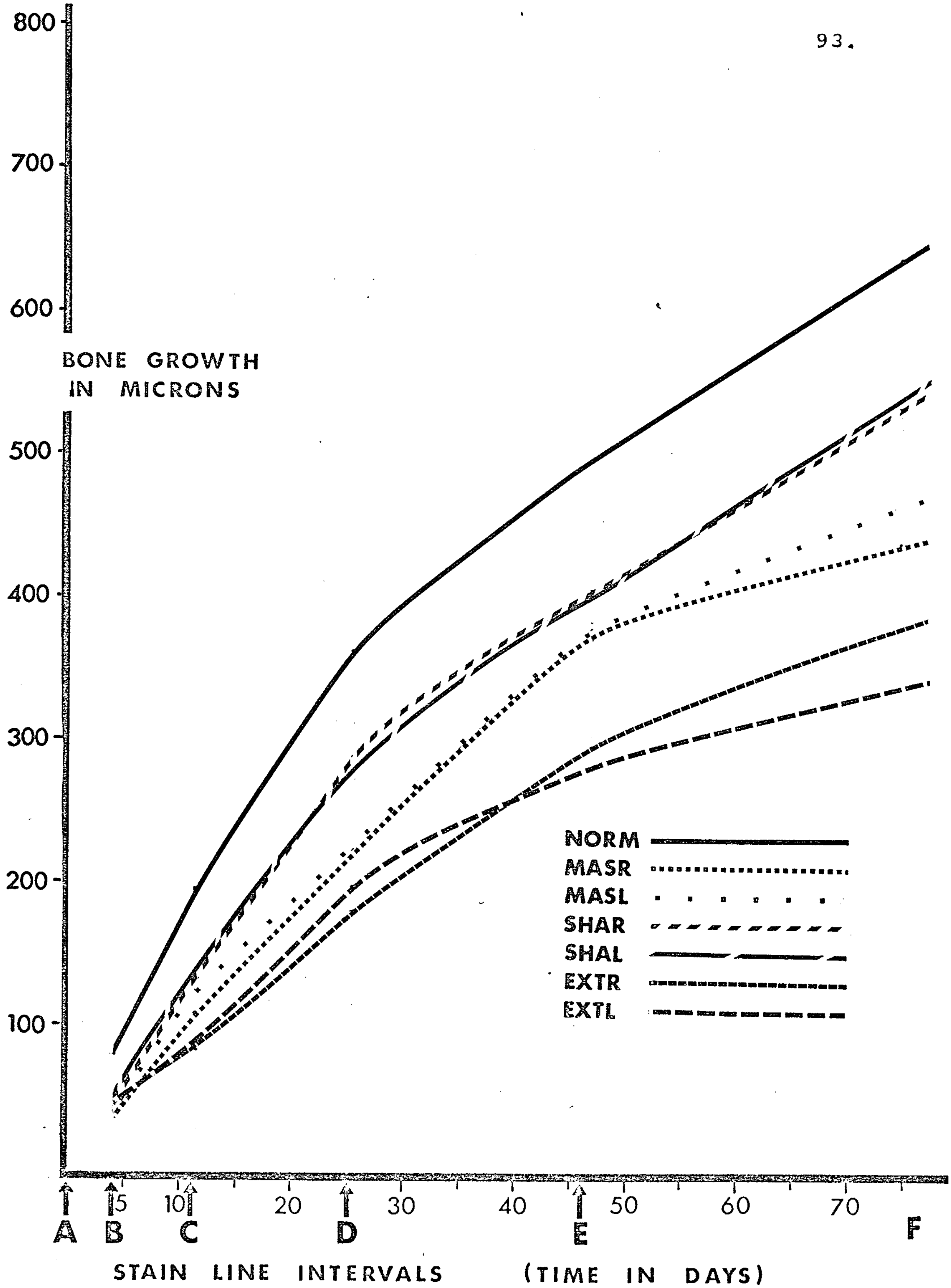


Figure 29. Cumulative Bone Apposition at Mandible Site 25.

example of the general reactive tendencies of each experimental group (Figure 29). All experimental groups grew slower than normal ($P = .05$ for masseterectomy and $P = .01$ for extraction group). The sham group was least affected while the extraction group rates were most retarded. There were no significant differences between growth increments for sides in any group.

MASSETER MUSCLE ATTACHMENTS

One of the more dramatic findings of the linear analysis was recorded for sites located along the masseteric ridge on the buccal surface of the mandible. The ridge itself served as an area of direct fibrous union of muscle and bone (tendon insertion). Bone growth was measured at Sites 16 and 22 in the First Molar and Third Molar Regions, respectively. The area of the buccal surface superior to the masseteric ridge also rendered a type of attachment for the masseter muscle. However, attachment at Sites 17 and 23 was mediated by the periosteum and did not involve direct fibrous union via Sharpey's fibers. The pattern of growth curves for the various experimental groups was similar (Figures 30, 31, 32 and 33) for both types of junction with exceptions noted for the unoperated side of the masseterectomy group.

Masseterectomy. The most important response was that of greatly increased growth of the operated side of the masseterectomy group. The curve of apposition did not reflect the usual biphasic pattern. Instead the "normal" shaped curve was achieved which was characterized by gradually decreasing increments of growth throughout the experimental period. The growth rate of the operated side was faster than normal at all except the EF intervals at the masseteric ridge sites. Site 16 showed this decline

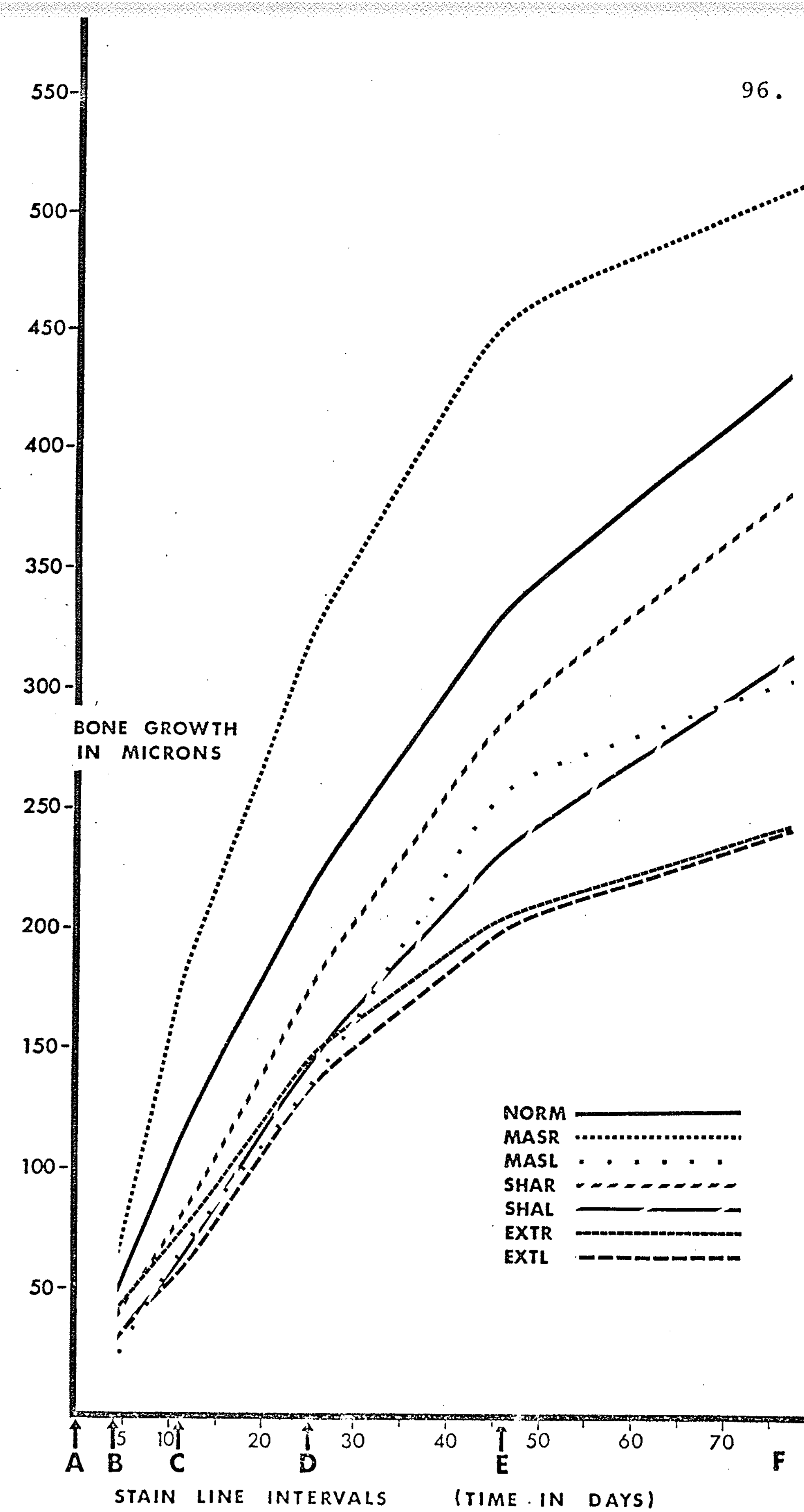


Figure 30. Cumulative Bone Apposition at Mandible Site 16.

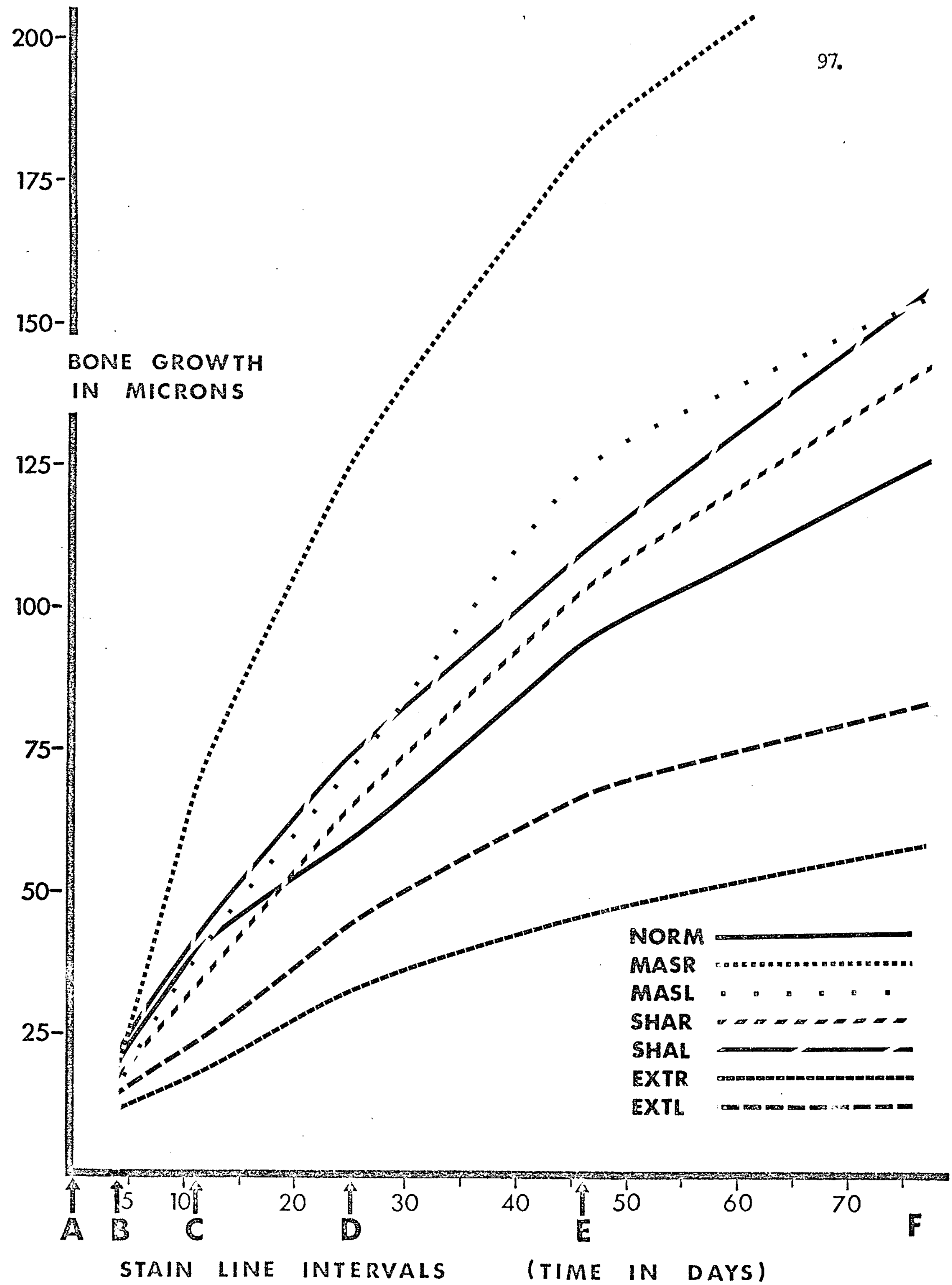


Figure 31. Cumulative Bone Apposition in Mandible Site 17.

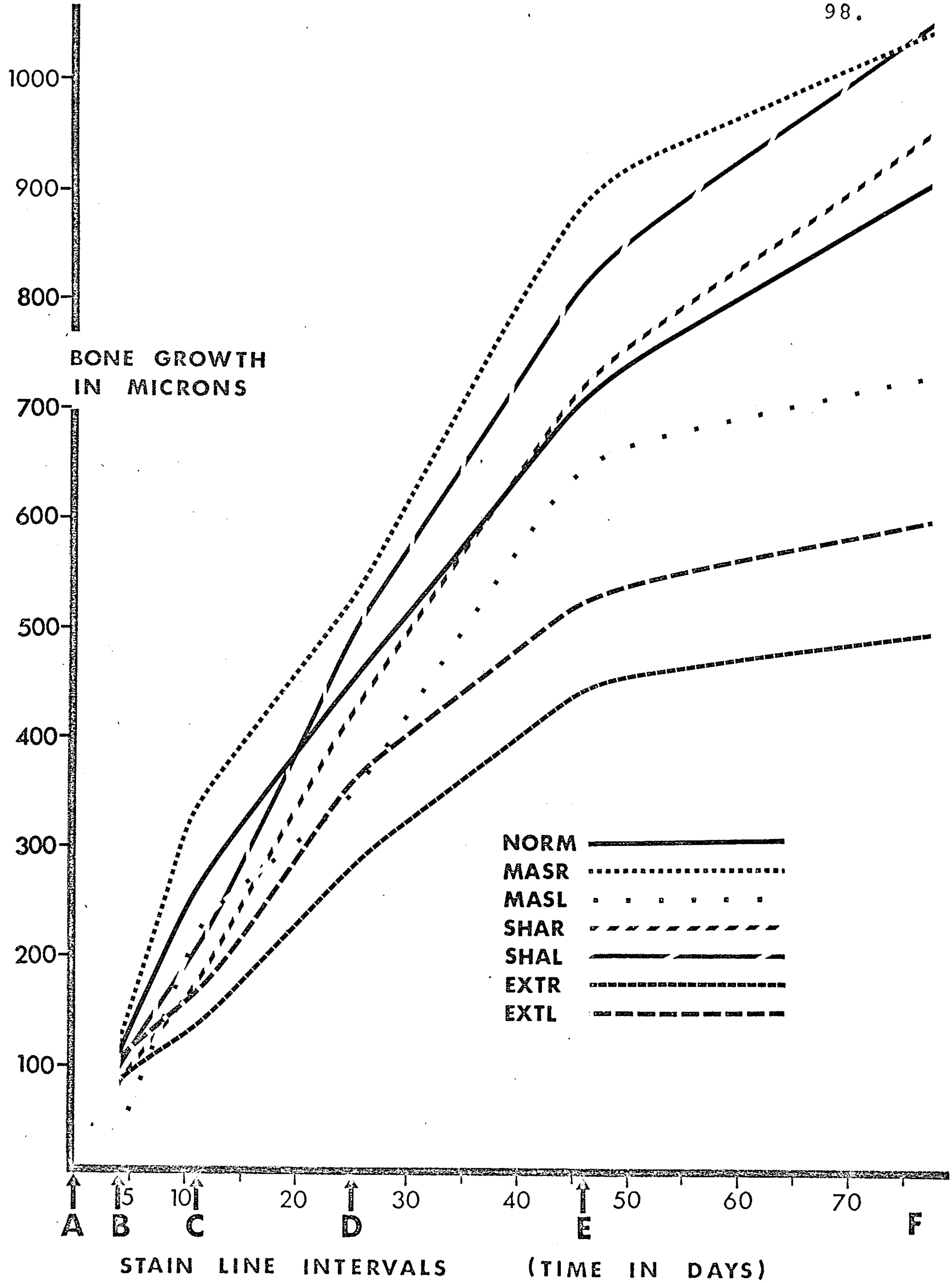


Figure 32. Cumulative Bone Apposition at Mandible Site 22.

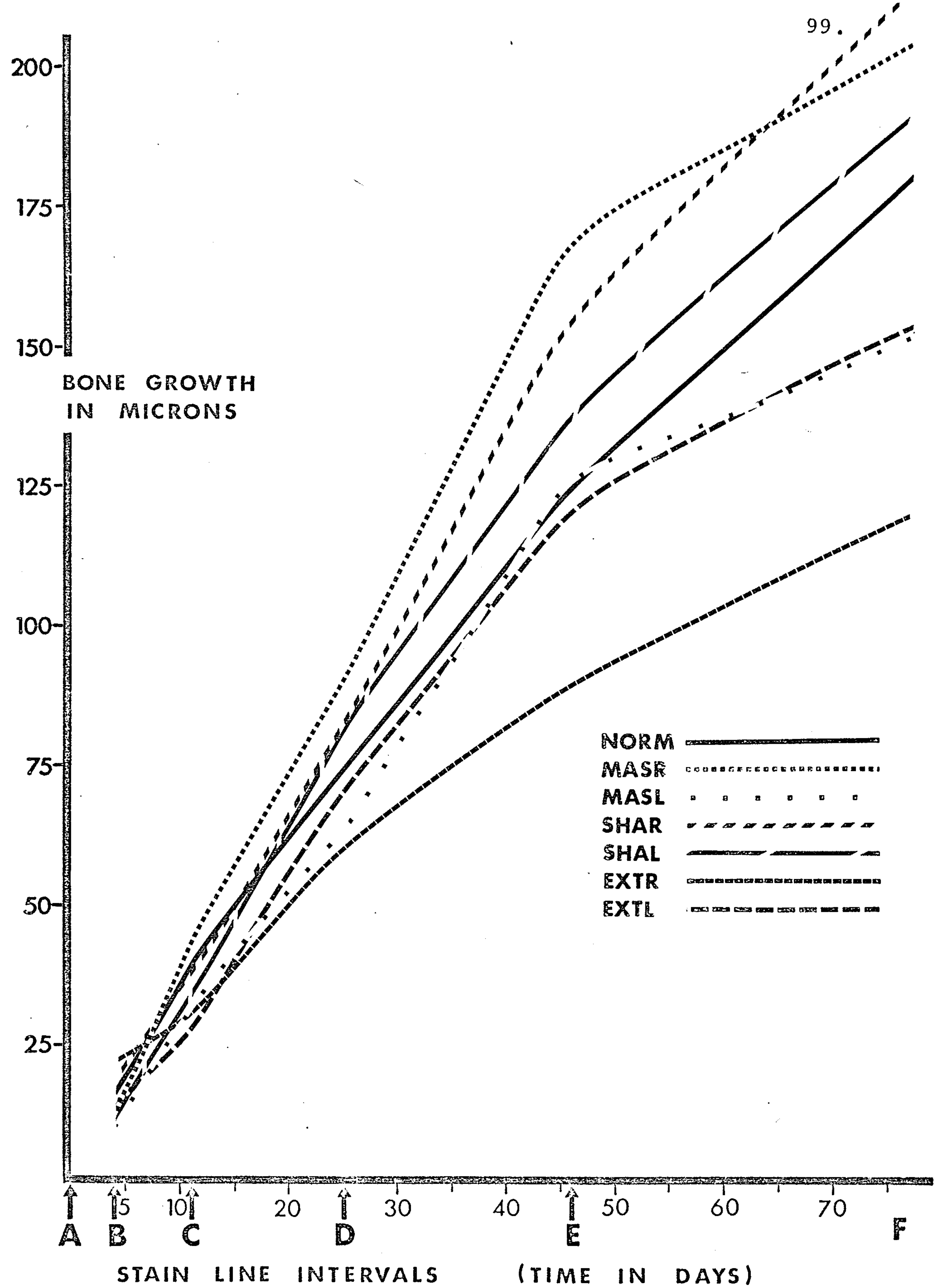


Figure 33. Cumulative Bone Apposition at Mandible Site 23.

TABLE VII

INCREMENTS OF BONE APPOSITION AT MASSETER ATTACHMENTS

MEANS AND STANDARD ERRORS IN MICRONS

	AB		BC		CD		DE		EF		
GROUP	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	TOTAL
MANDIBLE SITE 16											
NORM	53	4	66	5	106	9	118	12	87	9	430
MASR	63	10	125	21	146	17	132	18	50	6	516
MASL	23	2	46	9	69	9	129	19	39	9	306
SHAR	41	6	43	7	99	19	114	16	83	12	380
SHAL	31	6	36	6	84	16	89	13	73	14	313
EXTR	43	7	35	4	72	8	61	11	34	5	245
EXTL	32	4	29	3	78	10	68	5	36	4	243
MANDIBLE SITE 17											
NORM	20	2	20	2	20	2	36	4	29	4	125
MASR	19	5	51	9	58	11	59	6	40	9	227
MASL	15	4	24	2	34	7	56	7	26	5	155
SHAR	16	1	17	2	33	6	39	4	36	7	141
SHAL	21	3	21	3	33	4	37	5	43	7	155
EXTR	11	2	6	2	16	4	13	4	12	3	58
EXTL	14	2	9	2	22	6	23	4	15	4	83
MANDIBLE SITE 22											
NORM	106	6	152	11	184	12	262	17	170	17	874
MASR	107	14	232	13	188	21	362	38	126	28	1015
MASL	32	2	184	14	124	15	306	45	61	13	707
SHAR	78	7	93	12	241	31	309	36	197	25	918
SHAL	96	9	108	14	282	42	328	43	202	25	1016
EXTR	82	9	48	4	146	14	158	15	48	8	482
EXTL	100	9	62	5	192	18	167	13	58	10	579
MANDIBLE SITE 23											
NORM	16	1	23	2	36	2	52	6	50	4	177
MASR	11	2	32	5	50	5	80	14	31	5	204
MASL	9	1	22	2	34	5	62	9	24	6	151
SHAR	17	3	21	5	50	10	71	10	53	7	212
SHAL	12	3	21	3	50	6	58	5	48	6	189
EXTR	21	2	8	2	32	9	31	4	26	5	118
EXTL	13	2	14	3	44	5	53	4	29	5	153

significant at the 1 per cent level of confidence. The total amount of apposition was significantly greater at the 1 per cent level at Sites 16, 17 and 22 and at the 5 per cent level at Site 23. Examination of Table VII showing the mean linear values, reveals that the proportional increase in apposition was similar in the First Molar Region and in the Third Molar Region. It was of interest to note that the masseteric ridge was more pronounced in the Third Molar Region of the gross specimen.

An accompanying observation concerning apposition of the operated side of the masseterectomy animals was that a drastic change in growth direction occurred. Such a finding was rare and limited to the masseteric ridge sites. The growth direction altered from lateral (buccal) progression to a definite inferior course. The coordinate analysis polygons shown in Figure 34 demonstrate this important feature. The net effect of the alterations in rate and direction of bone apposition was the gradual obliteration of the masseteric ridge. There was no evidence of bone resorption on the buccal surface.

By contrast, the unoperated side of the masseterectomy group showed less growth than normal at the masseteric ridge sites and a growth rate either slightly above or approximately normal at the buccal surface sites. There was no alteration in the direction of bone apposition and the definition of

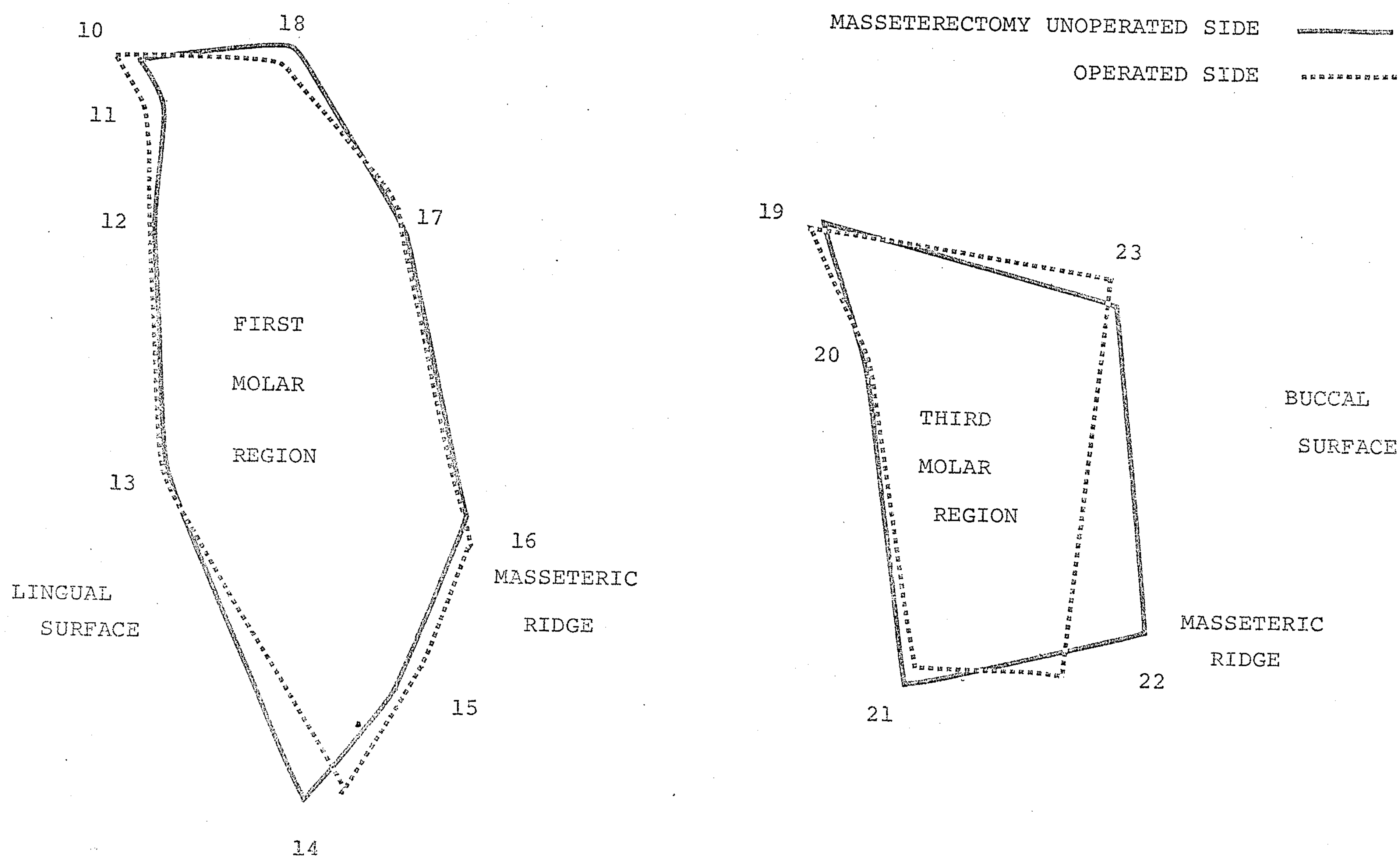


Figure 34. Coordinate E Line Polygons of Mandibular Molar Regions.

the masseteric ridge was maintained.

At the four sites measured, the unoperated side grew less than normal during the AB interval and exceeded the normal rate in the BC interval in accordance with its usual pattern. However, during the CD interval, these sites responded with a faster than normal rate at the periosteal attachment sites (not significant) and the more usual slower rate ($P = .05$) at the masseteric ridge sites. The unoperated side grew faster than normal at all four sites during the DE intervals, but reached a greater than normal amount of bone thickness only at Site 17 ($P = .01$). The EF interval was marked by the usual decline in masseterectomy rate ($P = .01$ at Sites 16, 22 and 23). The overall curves still reflected the basic biphasic pattern for the unoperated side.

The side differences in growth rate for the masseterectomy group were more pronounced at the masseteric ridge sites and generally exhibited a high significance ($P \ll .01$). The side differences at Sites 17 and 23 were significant at the 1 per cent level only for the BC and CD intervals, respectively.

<u>Sham</u>. The growth curves of the sham group did not reflect the response shown by the masseterectomy group. However, the sham operated side did grow more than the unoperated side at Site 16 and this difference was significant

(P = .05) during the AB interval. Such an acceleration may be interpreted as a healing response. The total apposition for the sham group at Site 16 was less than normal. After an initial retardation, the deposition rates for both sides of the sham group were more than normal at Site 22. The difference was significant (P = .01) for the left side during the CD interval. The rate differential between sides for the CD interval was also statistically significant (P = .05). This pattern was the reverse of that observed for the masseterectomy group at Site 22.

The periosteal attachment sites (17 and 23) showed no significant differences between normal and sham bone apposition increments.

Extraction. The general comparison of extraction group growth rates with normal revealed decreased apposition at all four sites. The amount of bone growth was the least of all the groups studied although the difference was not significant when comparison was made to the unoperated side of the masseterectomy group at Sites 16 and 23. No significant side differences were noted at Site 16. The remaining indicated slower growth of the operated side which was very significant ($P \ll .01$) for the AB, BC and CD intervals at Site 22 and the DE interval at Site 23. The DE interval at Site 17 also demonstrated the side difference (P = .05).

BUCCAL SURFACE - RAMUS REGION

An alteration in the depositional pattern, possibly as a response to lateral repositioning of the mandible resulting from unbalanced muscle pull, was noted upon examining growth at Sites 28 and 29. These sites were areas of periosteal attachment of the masseter muscle to the buccal surface of the mandible in the Ramus Region. The normal apposition amounts of these sites were quite similar although Site 28 demonstrated a quicker deceleration and consequently slightly less total growth (Figures 35 and 36).

Extraction. The extraction group curves also showed similar behavior between these sites. The extraction group grew less than normal during all intervals at both sites. These differences were more often significant at the 1 per cent level at Site 29. Such a finding of significant decrease throughout the experimental period did not represent the usual result which indicated significant differences only as a result of the surgical intervention at the beginning of the experiment and then again in the last third of the study period. The greater side differences found at Site 29 were significant during the EF interval as the operated side continued a faster growth rate. Amounts of total bone apposition were only slightly less at Site 29 for the extraction group.

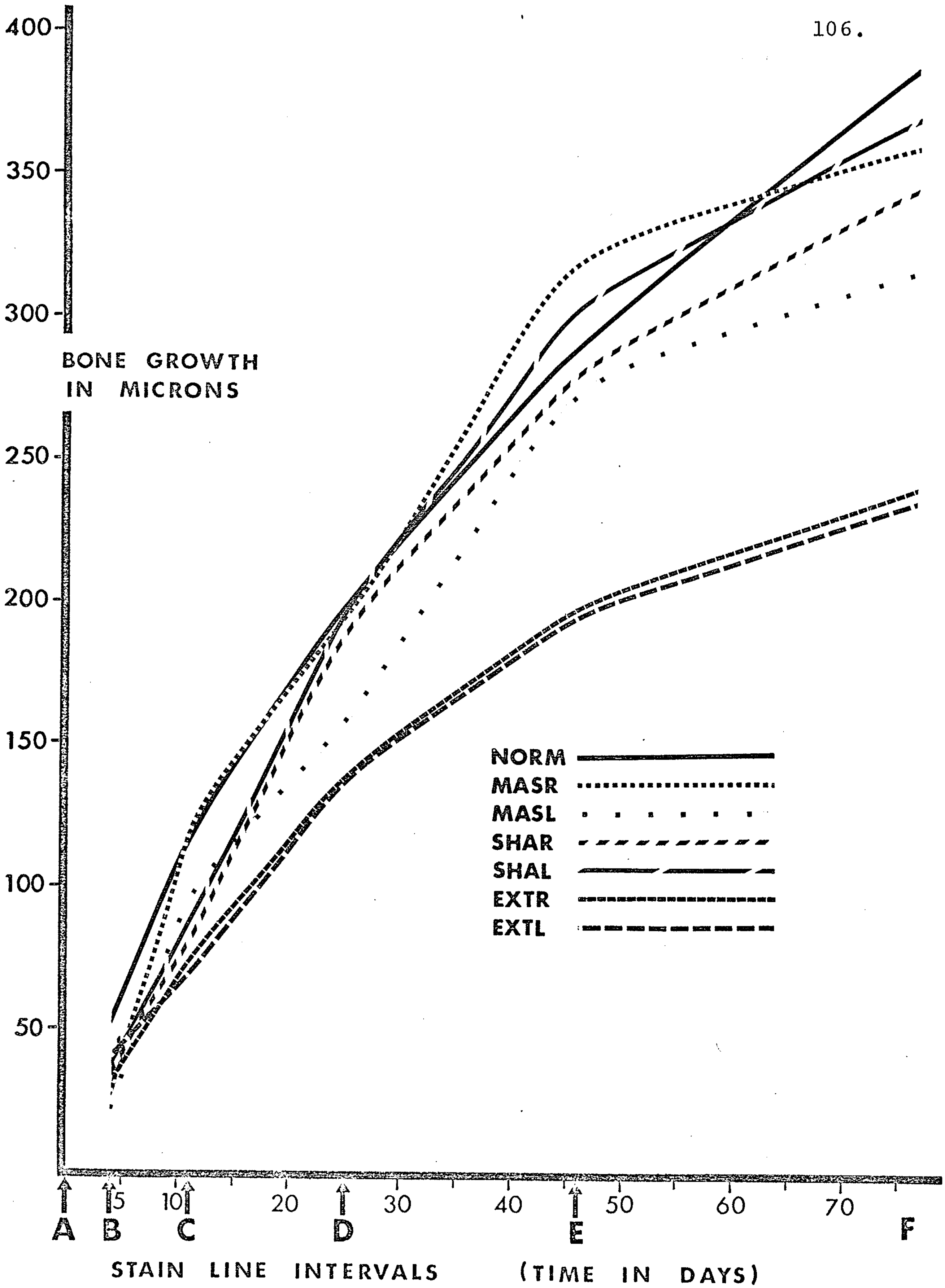


Figure 35. Cumulative Bone Growth at Mandible Site 28.

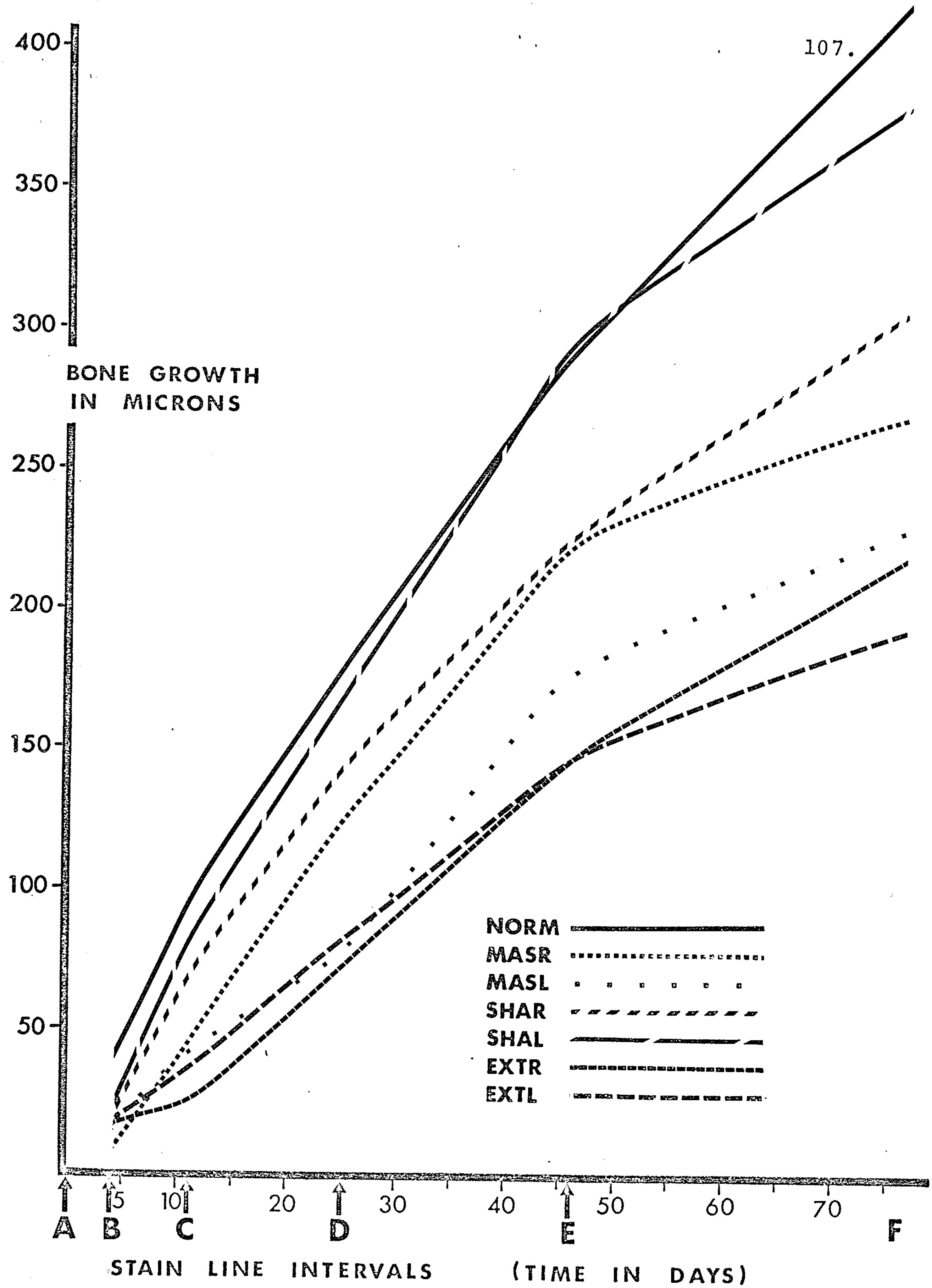


Figure 36. Cumulative Bone Growth at Mandible Site 29.

TABLE VIII

INCREMENTS OF BONE APPOSITION AT THE BUCCAL SURFACE OF THE RAMUS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
MANDIBLE SITE 27											
NORM	51	3	76	6	100	8	118	9	93	10	438
MASR	13	2	23	3	44	7	85	10	21	1	186
MASL	17	1	65	12	59	9	149	20	60	14	350
SHAR	49	7	49	7	110	16	132	18	131	16	471
SHAL	38	4	49	6	116	18	140	20	144	13	487
EXTR	33	5	29	4	86	10	113	13	71	8	332
EXTL	32	5	31	5	92	11	114	11	78	10	347
MANDIBLE SITE 28											
NORM	55	4	66	6	83	10	92	9	89	8	385
MASR	22	2	104	8	72	8	130	15	35	7	363
MASL	25	5	73	14	61	11	123	15	36	7	318
SHAR	36	8	47	9	111	23	93	13	59	9	346
SHAL	38	5	51	9	111	18	110	21	60	9	370
EXTR	29	3	47	10	63	8	64	10	38	4	241
EXTL	39	6	32	4	69	10	58	6	38	6	236
MANDIBLE SITE 29											
NORM	41	3	59	5	85	8	115	6	111	8	411
MASR	10	0	38	9	80	18	103	12	41	9	272
MASL	16	2	27	3	36	5	104	16	45	12	228
SHAR	22	4	50	10	76	12	84	12	73	10	305
SHAL	23	8	63	22	87	27	128	19	29	16	380
EXTR	17	6	8	4	49	12	77	10	66	8	217
EXTL	19	7	19	4	45	10	69	8	39	7	191

<u>Muscle Surgery</u>. Both sham and masseterectomy groups approximated overall normal growth at Site 28. Periods of significant differences from normal occurred in accordance with the usual accelerations and decelerations. The side difference in the masseterectomy group for Site 28 was extablished during the BC interval in which the right side showed the fastest growth of all groups (P = .01) and was significantly faster than the left side at the 5 per cent level of confidence. This increased growth response of the operated side was also observed at other sites where the masseter muscle had been removed. At Site 29, this side difference was most marked during the CD interval (P = .05).

The sham group behaved differently and showed no side differences at Site 28. At Site 29, the side difference was marked during the DE interval (P = .05) but the unoperated side was growing faster than the operated side. The differences between the operated sides of the masseterectomy and sham groups were significant for BC and AE intervals at Site 28, but not for Site 29.

At Site 28, the masseterectomy group adhered more closely to normal amounts of total bone apposition while at Site 29, the disparity approached half of total normal growth. That is, growth was proportionately greater at the more superior site and consequently, the overall shape of this cross-section showed a greater buccal convexity in

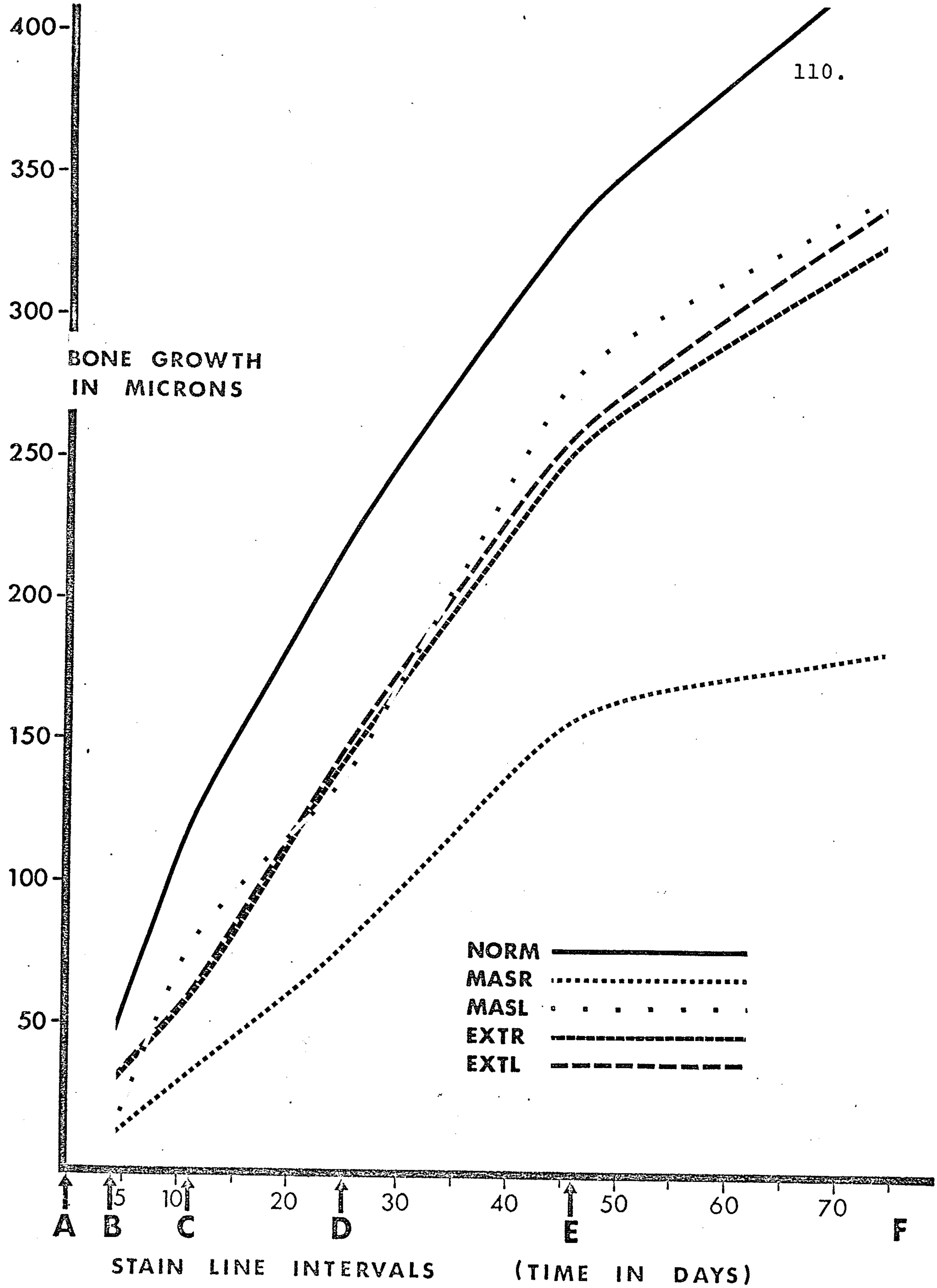


Figure 37. Cumulative Bone Growth at Mandible Site 27.

the masseterectomy group. The importance of this growth pattern alteration will be clarified in the discussion section.

BUCCAL SURFACE - RETROMOLAR REGION

The linear analysis of bone apposition at Site 27, located near the inferior border, was characterized by the usual growth patterns for all groups except the operated side of the masseterectomy group (Figure 37). This side did not demonstrate its usual increase in apposition rate during the BC interval. On the contrary, there was a marked retardation in growth statistically significant at all; except the DE intervals at the 1 per cent level of confidence. Such a dramatic departure from expected behavior indicated a specific response to removal of the masseter muscle.

UNALTERED MUSCLE ATTACHMENTS

There were two sites studied in the mandible that served as attachments for the digastric muscle (suprahyoid group) and the temporalis muscle. These were Sites 6 and 24, respectively, and their growth curves are presented in Figure 38. A distinctive pattern of group interactions was depicted for Site 6. During the AB interval, all experimental groups grew much slower than normal (P = .01). The unoperated side of the masseterectomy group demonstrated its usual "catch up" phase during the BC interval (P = .01), but the operated side acceleration managed only to equal the normal growth rate. This finding was in contrast to observations made at altered muscle attachment sites.

Rate decreases for the sham group were significant for the right side (P = .05) during the BC interval and more so for the extraction group (P = .01). The extraction group did not demonstrate any significant side differences. The CD interval showed the common finding of an acceleration of the sham group rate (P = .05) that was maintained through the DE interval. The sham group rates were similar to those of the normal group during the EF period.

The DE interval was a recovery period for the masseterectomy group. The left side's increase was significant at the 1 per cent level. The extraction group, however, showed a non-significant decrease from normal. Both masseterectomy

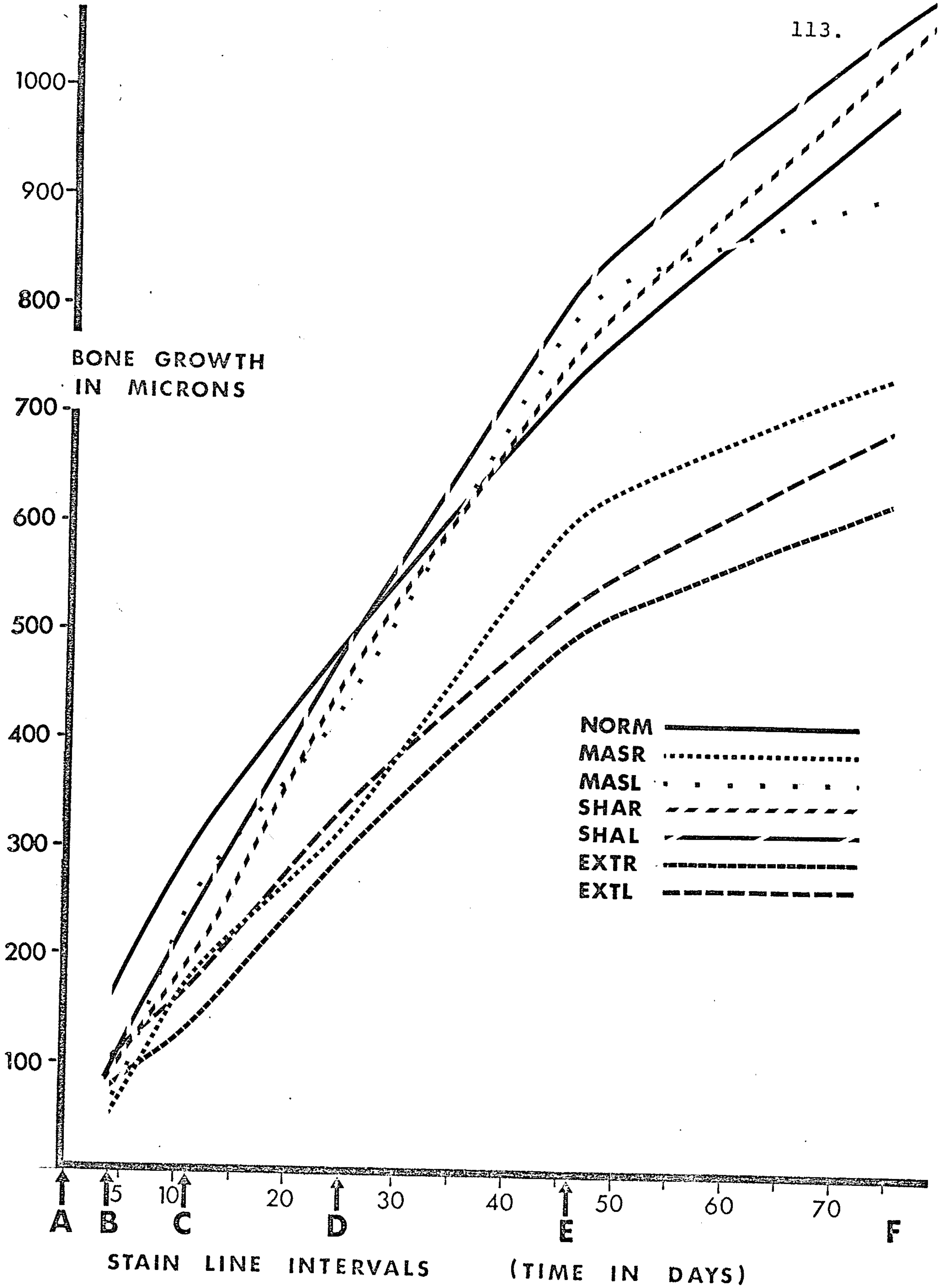


Figure 38. Cumulative Bone Growth at Mandible Site 6.

TABLE IX

INCREMENTS OF BONE APPOSITION AT UNALTERED MUSCLE ATTACHMENTS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
MANDIBLE SITE 6											
NORM	150	8	147	8	189	9	249	15	240	18	975
MASR	46	7	128	18	141	18	292	36	119	21	726
MASL	51	5	203	12	162	18	382	35	95	16	893
SHAR	80	11	108	19	260	39	307	40	263	47	1018
SHAL	86	10	140	19	257	38	342	46	223	42	1048
EXTR	71	28	53	18	166	47	207	58	114	53	611
EXTL	99	15	67	11	168	15	196	20	146	23	676
MANDIBLE SITE 24											
NORM	88	5	134	11	196	19	264	17	241	12	
MASR	20	8	63	11	76	18	188	18	63	9	
MASL	13	3	48	3	97	13	194	28	66	12	
SHAR	50	0	150	0	195	105	204	25	195	20	
SHAL	40	0	135	0	178	98	194	16	187	29	
EXTR	-	-	-	-	150	0	218	21	164	14	
EXTL	75	0	40	0	185	0	203	26	165	22	

and extraction groups experienced a severe rate decline during the EF period (P = .01). In overall growth, there was no significant difference between the operated side of the masseterectomy group and the extraction group values.

From the observation that the operated side of the masseterectomy and both sides of the extraction group showed less net growth than normal, it may be concluded that there was no evidence to support the idea of growth stimulation occurring in response to an increase of functional demand at this unaffected site of muscle attachment.

The temporalis muscle attachment (Site 24) presented still other modes of adaptation. There were no side differences of significance. The site was subject to resorption from the incisor socket surface and only intervals DE and EF were represented by sufficient values for comparison.

During the DE interval, the masseterectomy group and the unoperated side of the sham group showed significant decrease from the normal growth rate (P = .05). The other experimental groups also grew less than normal, but the disparity was not significant. Both extraction and masseterectomy groups grew significantly less than normal at the 1 per cent level of confidence. The sham group also displayed a slower growth rate but only that of the left side was significantly different from normal (P = .05). In addition, it was observed that the masseterectomy group had shown the least deposition during the EF interval (P = .01).

INFERIOR BORDER

The nature of the remodelling changes used to achieve relocation corrections of inferior border morphology were clarified by comparison of apposition rates at Sites 14, 21, 26 and 30 (Figs. 39 — 43). Normal growth consisted of a progressive decline in bone apposition from the First Molar, to the Third Molar, to the Retromolar Regions; and an increase in the Ramus Region rate to the values of the First Molar Region. At no point along the external cortex of the inferior border was there evidence of bone resorption. A disruption of the normal intersite growth relationships occurred among the experimental groups.

Masseterectomy Group

All sites demonstrated the alternating periods of more rapid and slower than normal bone deposition which was characteristic of masseterectomy group findings. Although the total amount of growth was less than normal at all inferior border sites, only Site 26 grew slower during the entire experimental period. Side differences were significant only for the EF interval ($P = .05$) favoring the operated side. In contrast, the other sites (anterior and posterior to the antegonial notch) shared a common finding of faster than normal rates during the BC and DE intervals and slower rates during the AB, CD and EF intervals. The significance of these alterations varied slightly from site to site (Table X).

The more pronounced rate decline of the operated side at Sites 21 and 30 was not found at Site 14. These rate differences between sides became smaller as the experimental period progressed. The growth differences between left and right sides observed at Sites 21, 26 and 30 account for the alteration seen in the curvature of the antegonial notch area of the gross specimen.

Extraction Group

The extraction group demonstrated the smallest increments of bone apposition at each site along the inferior border. At Site 26, the rate pattern was the same as that of the masseterectomy group; an early greater decline of growth on the operated side followed by a greater rate of growth for this side during the DE and EF intervals, which almost reached statistical significance. The overall discrepancy between sides was not large at the other inferior border sites in accordance with the minimal alterations occurring in the antegonial notch morphology. However, the left side grew faster than the right during the CD interval at Site 21 (P = .05) to compensate for an earlier rate deficiency.

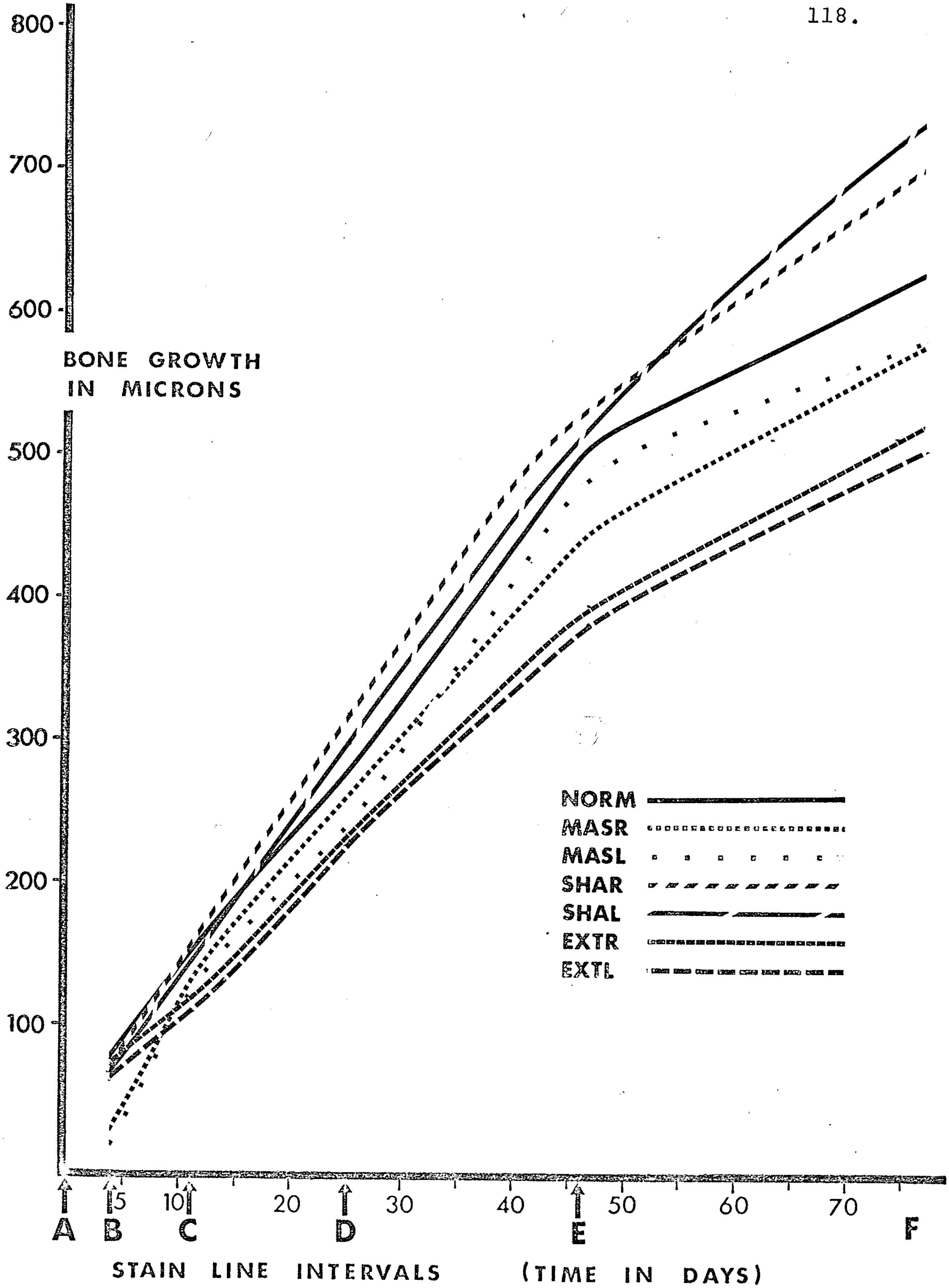


Figure 39. Cumulative Bone Growth at Mandible Site 14.

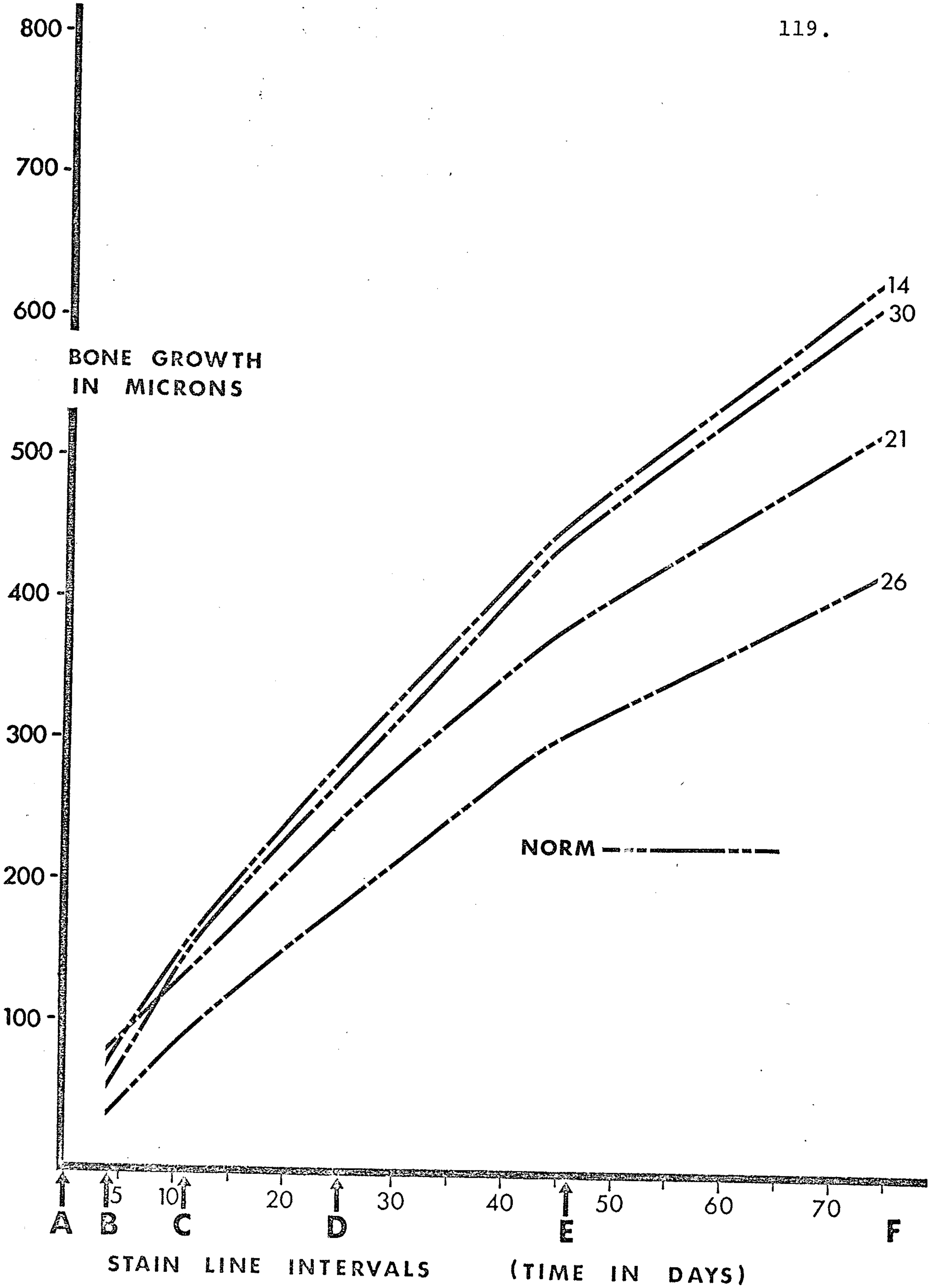


Figure 40. Comparison of Normal Growth at Inferior Border Sites.

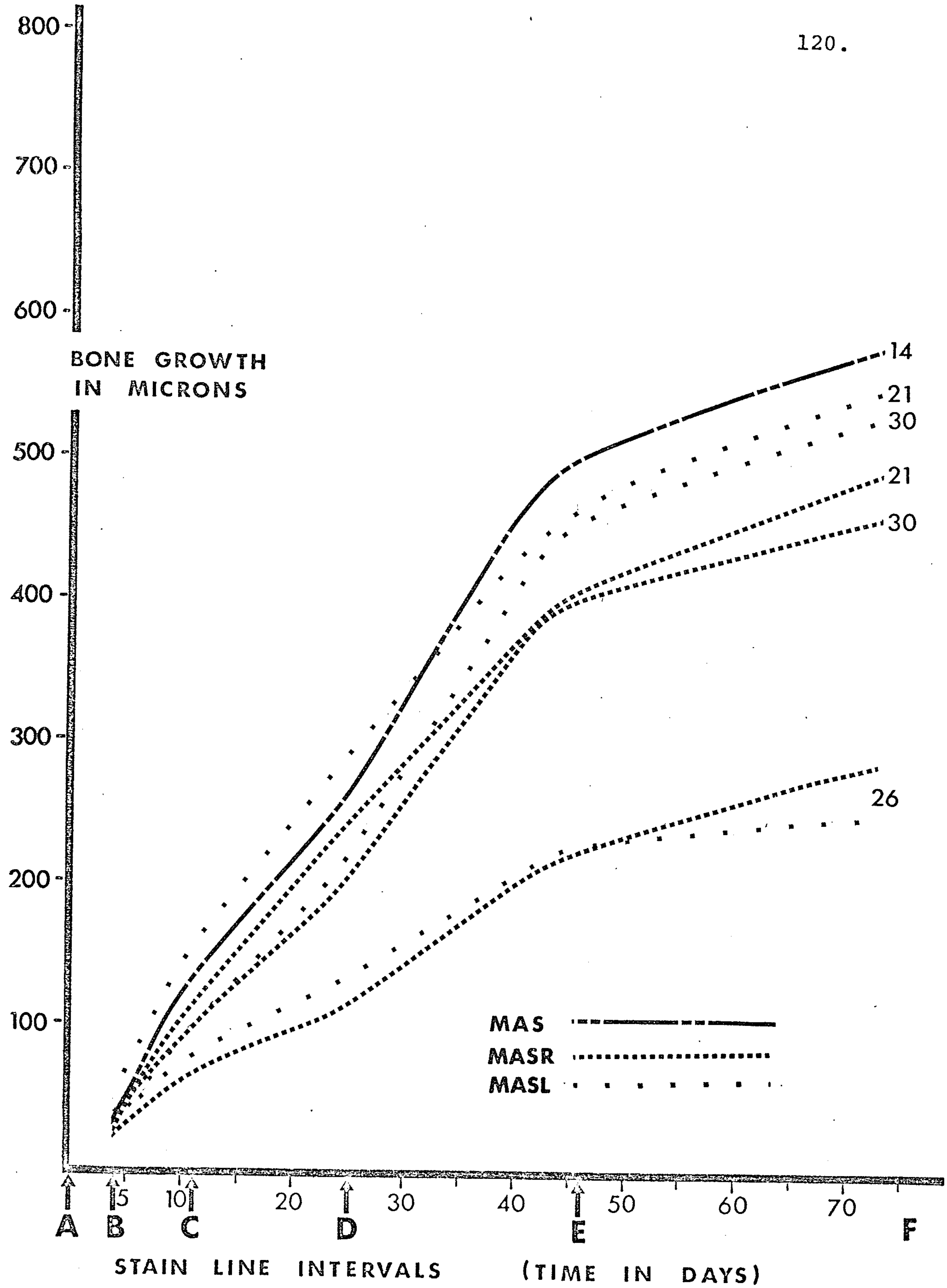


Figure 41. Comparison of Masseterectomy Group Growth at Inferior Border Sites.

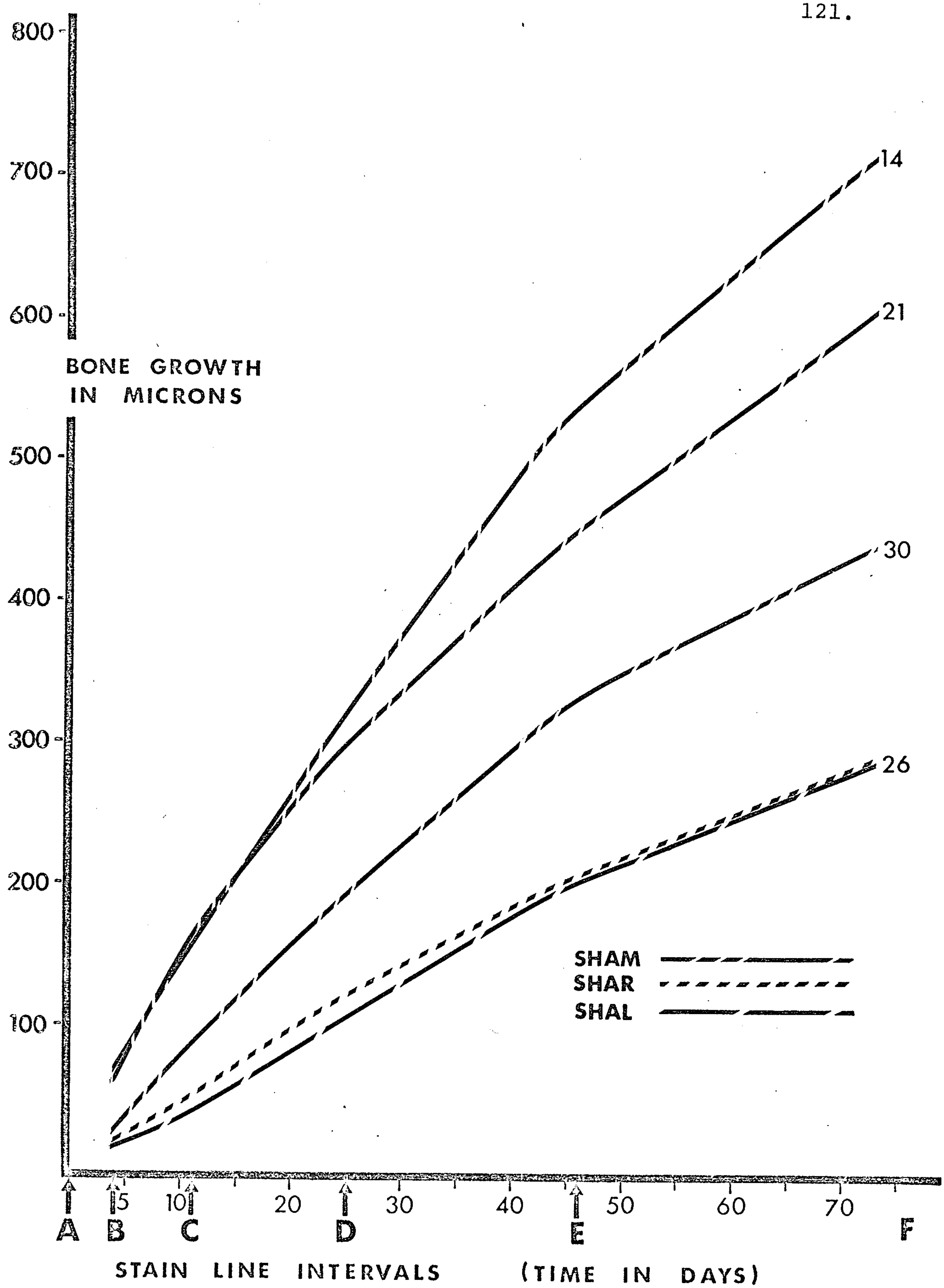


Figure 42. Comparison of Sham Group Growth at Inferior Border Sites.

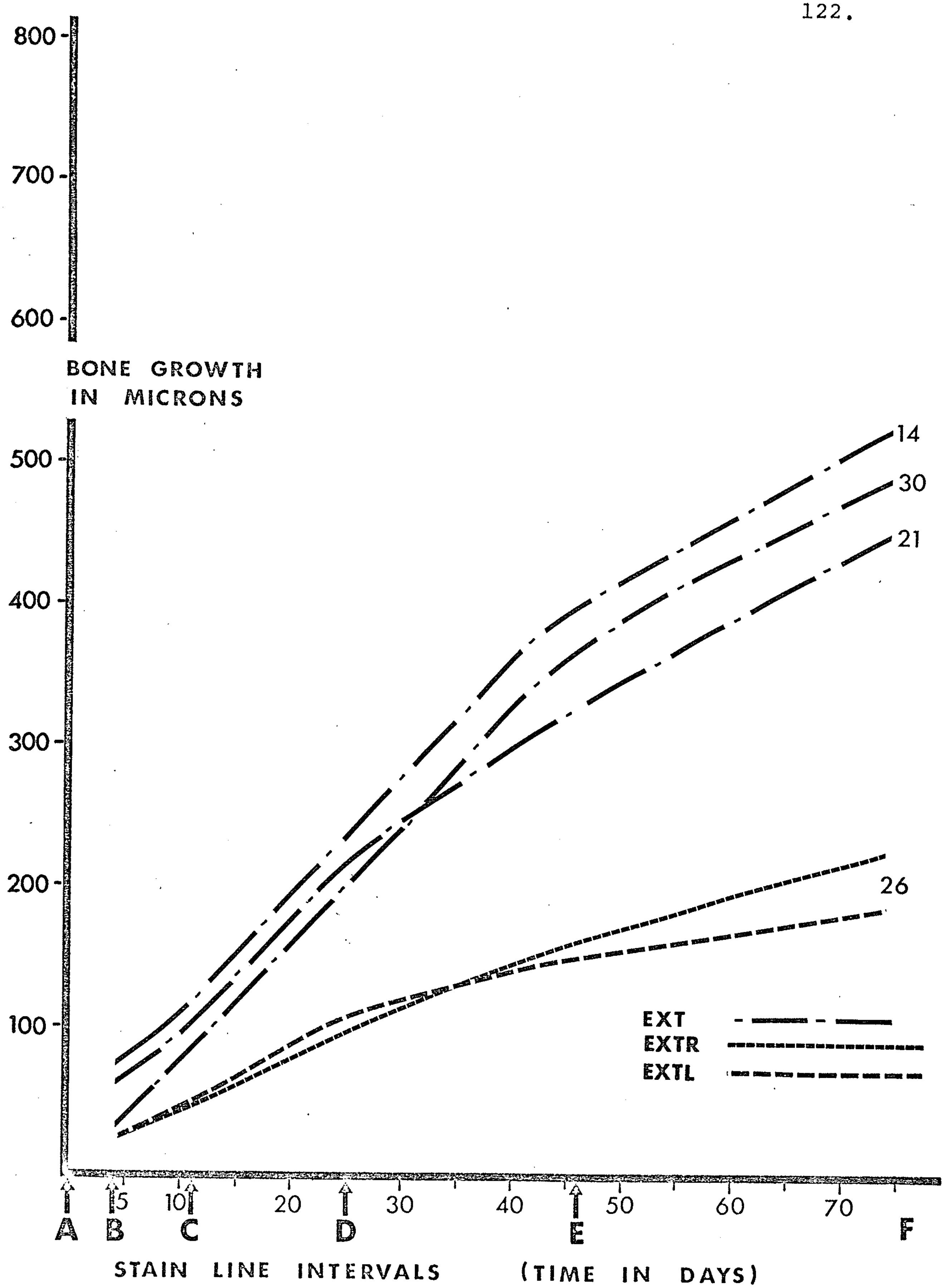


Figure 43. Comparison of Extraction Group Growth at Inferior Border Sites.

TABLE X

INCREMENTS OF BONE APPOSITION AT THE INFERIOR BORDER

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					MANDIBLE SITE 14						
NORM	80	5	78	4	126	12	173	12	186	15	643
MASR	27	3	110	12	131	13	252	18	60	12	580
MASL	17	3	118	13	110	16	256	27	83	15	584
SHAR	79	10	85	12	164	22	216	21	160	41	704
SHAL	71	7	80	10	153	28	229	26	202	35	735
EXTR	79	7	43	8	117	12	166	8	120	12	525
EXTL	68	5	44	5	124	6	155	10	124	12	515
					MANDIBLE SITE 21						
NORM	86	6	52	17	108	22	139	24	146	34	531
MASR	32	2	78	9	127	17	169	17	85	15	491
MASL	48	28	103	28	133	16	185	21	80	15	549
SHAR	60	4	94	9	141	16	148	19	161	19	604
SHAL	68	8	109	13	129	13	149	13	156	19	611
EXTR	74	15	40	6	92	13	112	10	116	12	434
EXTL	48	8	38	4	138	11	108	8	124	8	456
					MANDIBLE SITE 26						
NORM	39	2	57	5	86	8	128	8	116	10	426
MASR	23	5	41	8	43	5	119	13	52	9	278
MASL	30	2	46	7	55	6	92	14	28	5	251
SHAR	24	4	28	5	72	17	82	8	83	5	289
SHAL	18	3	21	4	67	15	97	17	84	14	287
EXTR	23	4	21	3	53	11	66	18	56	12	219
EXTL	22	4	22	4	63	8	47	8	31	8	185
					MANDIBLE SITE 30						
NORM	60	9	95	7	122	11	171	18	175	23	623
MASR	32	9	65	45	95	25	213	26	56	13	461
MASL	25	5	70	26	113	48	250	37	76	17	534
SHAR	35	3	60	24	96	36	126	20	116	24	423
SHAL	25	6	60	33	103	56	138	23	112	19	438
EXTR	30	0	20	0	60	0	156	28	98	19	364
EXTL	-	-	-	-	125	25	144	19	88	22	-

Sham Group

The increment curves of the sham group do not reflect the "alternating" nature of the masseterectomy curves rather they approximate the normal curvature. A greater decline in the unoperated side rate during the BC interval (P = .05) at Site 26 was the only side discrepancy noted. The order of sites according to total bone apposition was altered from normal. Site 30 did not show an apposition total almost equal to Site 14, but rather was intermediate in rank between Site 21 and Site 26.

A most interesting finding was the increase over normal of bone additions at Sites 14 and 21, resulting from faster rates in the early stages of the experimental period. In contrast, the early rates at Sites 30 and 26 were much slower than normal (P = .01).

Group Comparison

The general relationship of group growth curves for inferior border sites is demonstrated by those of Site 14 in Figure 39. Due to rate increases during the CD and DE intervals, the sham group attained a larger than normal amount of bone growth. The alternating rate reductions and accelerations caused the curve of the masseterectomy group to cross the normal curve during the DE and EF intervals. The extraction curve stayed below the normal throughout the entire experimental period and exhibited the least amount of total apposition of all the groups. The differences in rates between sides were not pronounced.

The pattern at Site 21 was similar to that described for Site 14. At Site 26, the same relationships held amongst experimental groups although side differences were significant, but the normal group demonstrated more than 1/3 greater total apposition. This may, in part, be due to the cross-sectional sample used to determine the normal growth curve for this site. Comments on the effect of anteroposterior translation and relocation with age are to be found in the discussion. A slightly greater reduction in total growth at Site 30 was registered for the experimental groups than might be expected from observation of the curve pattern of Site 14. The influences prompting greater than normal growth do not appear to be operative at Site 30. However, during the DE interval, the masseterectomy group underwent a dramatic growth spurt so that the left side value reached the amount of normal apposition. There was a significant difference between sides and although the operated side also reflected this "spurt", it grew much less ($P = .01$) than the unoperated side in both DE and EF intervals.

ALVEOLAR PROCESS

The functional alterations were expected to produce abnormal rates of molar tooth eruption. The rate of apposition at the gingival border of the alveolar process gave an indication of the eruptive activity of the teeth. Sites 12, 18, and 19 are the lingual and buccal alveolar processes adjacent to the first molar; and the lingual alveolar process of the third molar, respectively. The growth curve pattern for each group was consistent throughout these three sites. Site 19 illustrates these patterns in Figure 44. The operated side of the extraction group showed a dramatic increase in alveolar bone deposition; significant at $P = .01$, while its unoperated side was not significantly different than normal in apposition rate. The difference between sides was highly significant ($P < .01$ at all intervals.

In contrast, the masseterectomy curves demonstrated no large differences between sides and a generalized growth retardation significant at $P = .01$. The sham and normal curves were quite similar.

The total amount of normal growth ranged from least at the buccal of the first molar to more at the lingual of the third molar to most at the lingual of the first molar. At each site all curves showed an early period of rapid deposition and a later decline in rate.

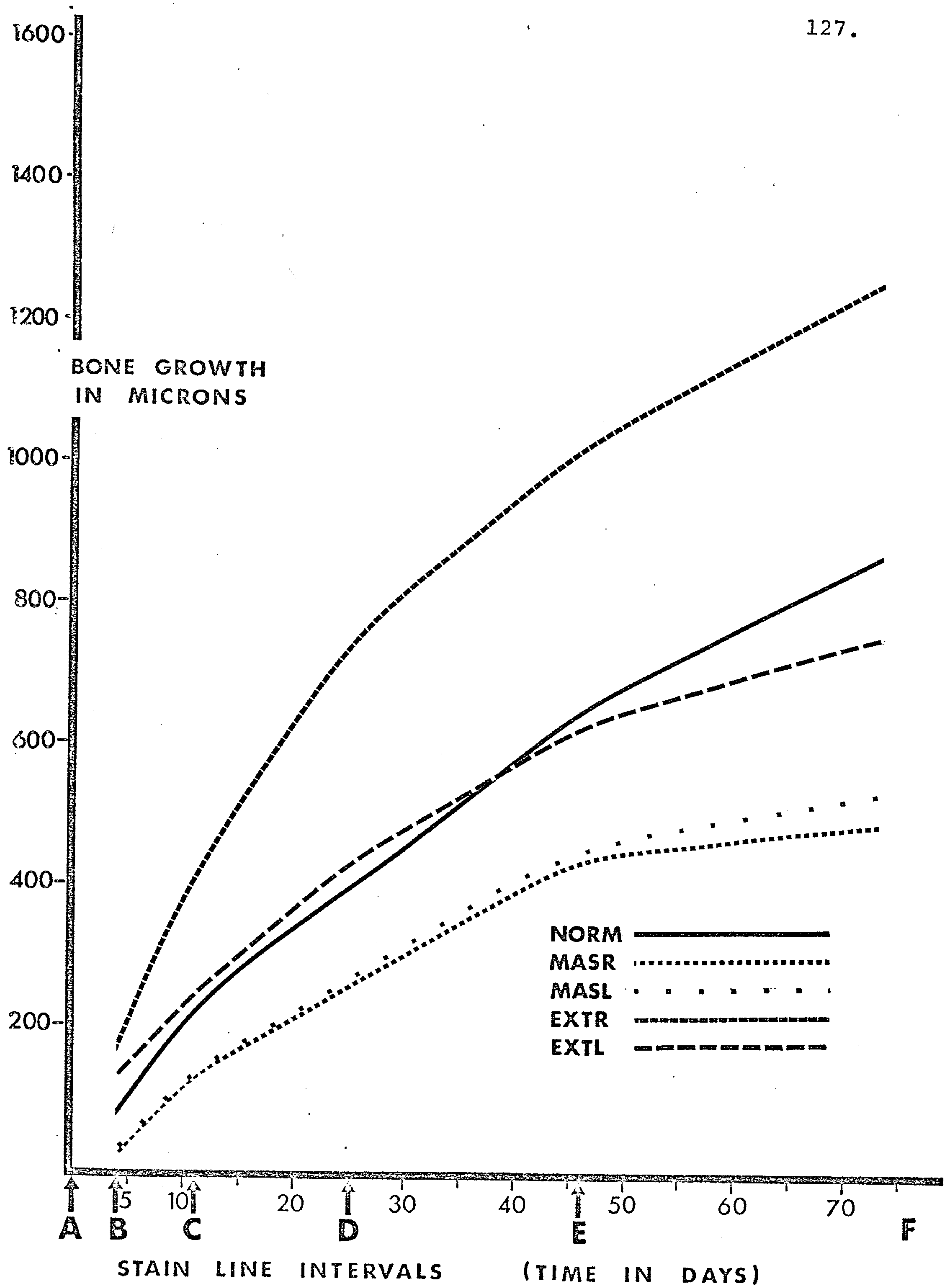


Figure 44. Cumulative Bone Growth at Mandible Site 19.

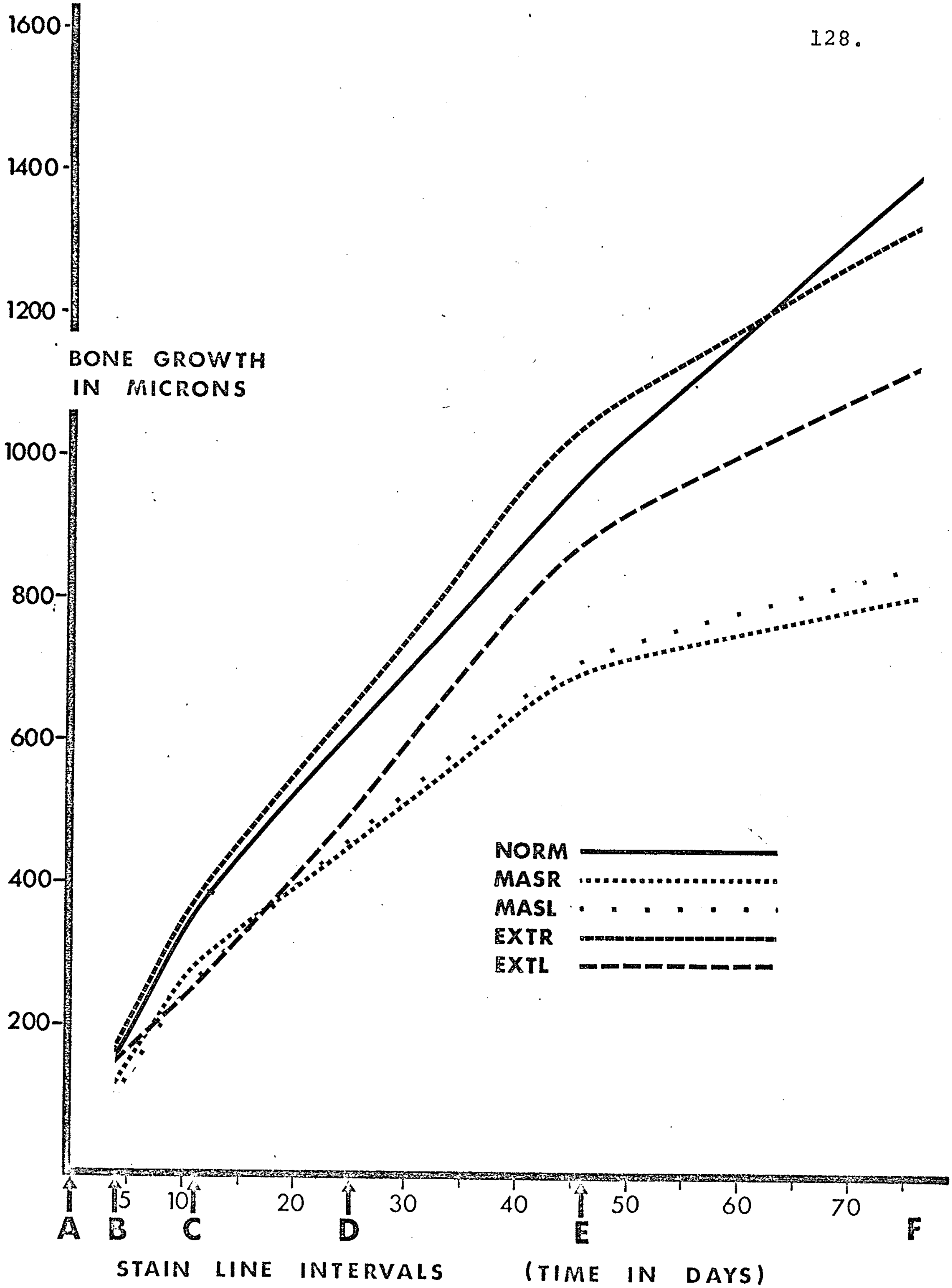


Figure 45. Cumulative Bone Growth at Mandible Site 12.

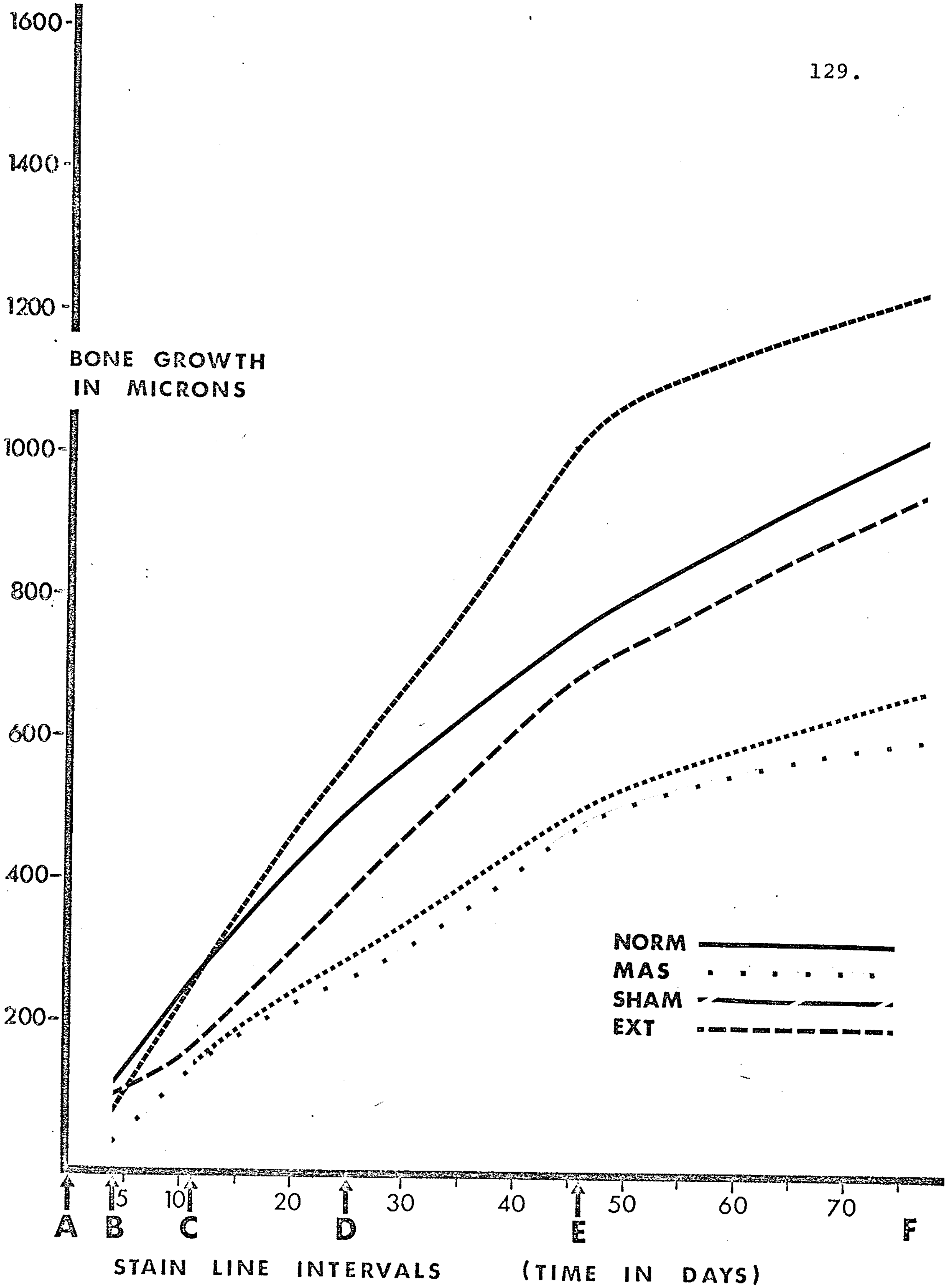


Figure 46. Cumulative Bone Growth at Mandible Site 18.

TABLE XI

INCREMENTS OF BONE APPOSITION AT THE ALVEOLAR PROCESS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
MANDIBLE SITE 12											
NORM	154	6	217	14	242	19	370	23	437	25	1420
MASR	118	20	171	19	166	24	258	43	99	22	812
MASL	89	14	184	12	195	10	265	38	119	41	852
SHAR	136	14	194	16	337	44	351	42	408	78	1426
SHAL	137	9	188	17	312	35	341	41	318	89	1296
EXTR	170	14	218	42	268	59	406	99	262	50	1324
EXTL	142	11	116	5	246	40	398	93	222	46	1124
MANDIBLE SITE 18											
NORM	117	6	159	12	238	25	261	15	269	22	1044
MASR	36	8	111	16	154	23	225	36	149	24	675
MASL	38	7	112	19	127	14	220	32	115	18	612
SHAR	100	19	167	19	281	32	329	41	225	18	1102
SHAL	76	10	140	19	242	20	342	55	236	36	1036
EXTR	83	22	173	55	325	97	490	122	164	48	1235
EXTL	98	13	68	11	226	21	326	98	226	30	944
MANDIBLE SITE 19											
NORM	103	6	202	15	211	14	339	14	280	10	1135
MASR	33	10	145	18	161	16	244	21	58	14	641
MASL	27	6	152	26	174	17	249	29	88	20	690
SHAR	69	10	199	22	281	26	314	25	218	22	1081
SHAL	59	11	196	18	278	19	313	20	204	20	1050
EXTR	231	18	319	28	429	26	358	35	302	17	1639
EXTL	169	12	154	14	243	18	248	16	171	14	985

DENTIN FORMATION

It was expected that alteration of the masticatory abilities would produce changes in tooth eruption rates and possibly tooth formation as well. Dentin formation was measured in the first mandibular molar at the lingual cusp tip (Site 10) and cervical margin (Site 11). The deposition increment curves for these sites are illustrated in Figures 47 and 48. The amount of dentin formation was seen to be greater at the cusp tip but the interrelationships between groups was similar for both sites. The curve configurations were distinctly different from the usual skeletal growth patterns. The masseterectomy curve did not manifest a biphasic pattern and all curves demonstrated linear growth in the early periods with an abrupt rate decline occurring during the EF period. The rate decline was especially marked for the extraction group. To assess the importance of the age differential, between extraction and normal animals, in relation to the finding of least dentin formation in the extraction group Figure 49 is presented. This is a composite graph of normal and extraction curves for both sites. The extraction curves have been adjusted to eliminate the six day age difference. It can be readily ascertained that the significance of the decline in dentin formation was not due to the age variation.

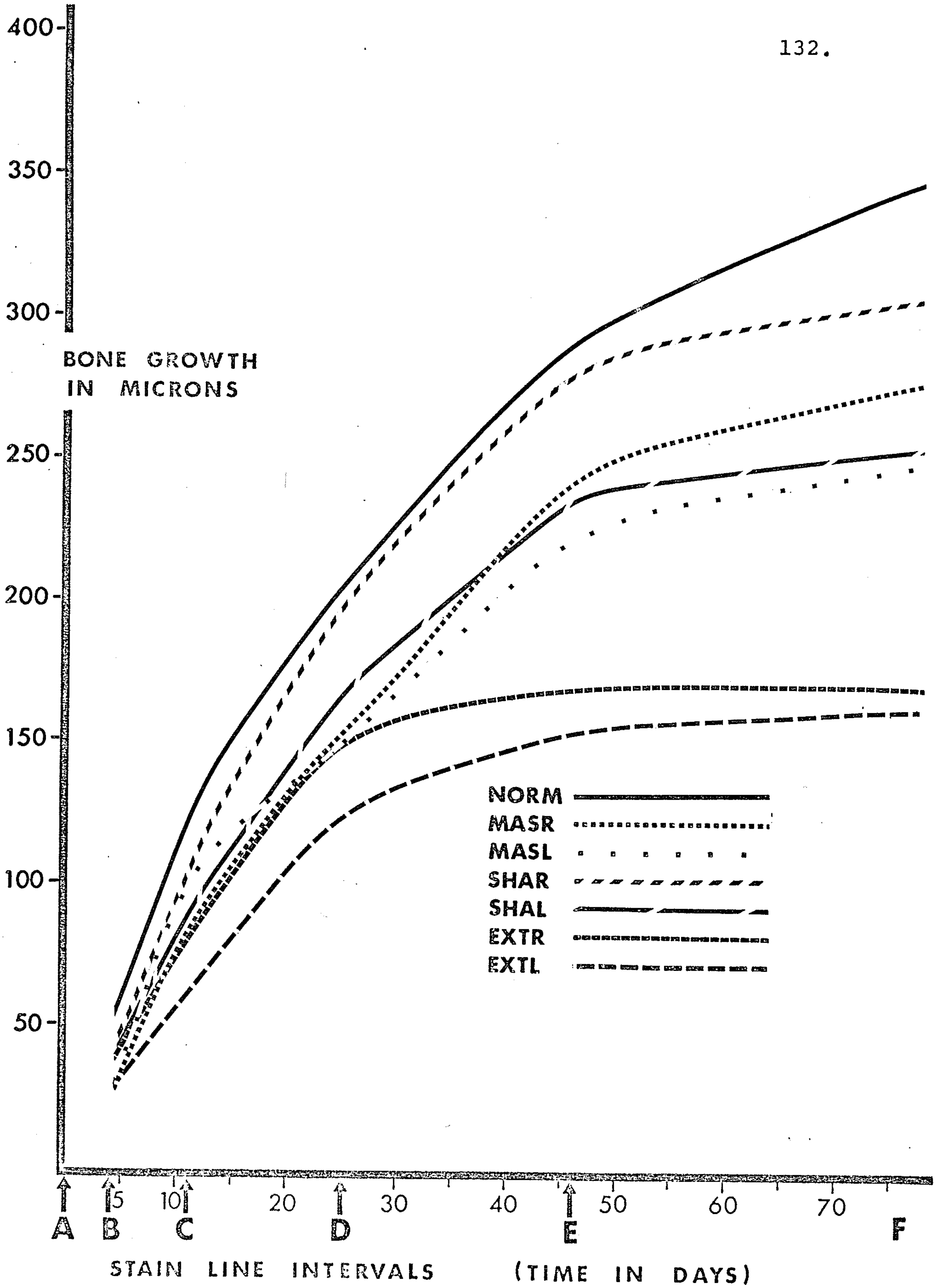


Figure 47. Cumulative Dentin Apposition at Mandible Site 10

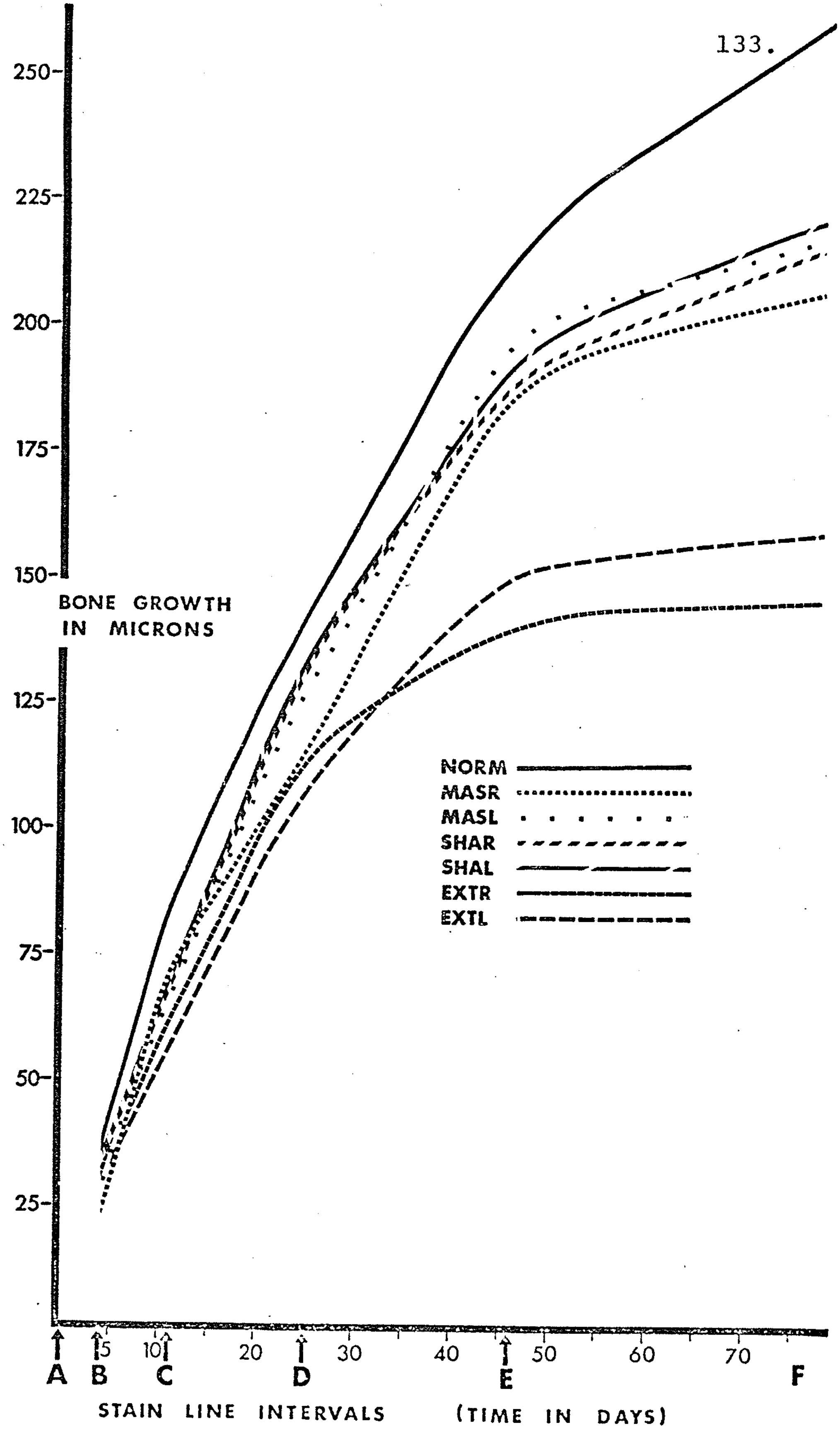


Figure 48. Cumulative Dentin Apposition at Mandible Site 11

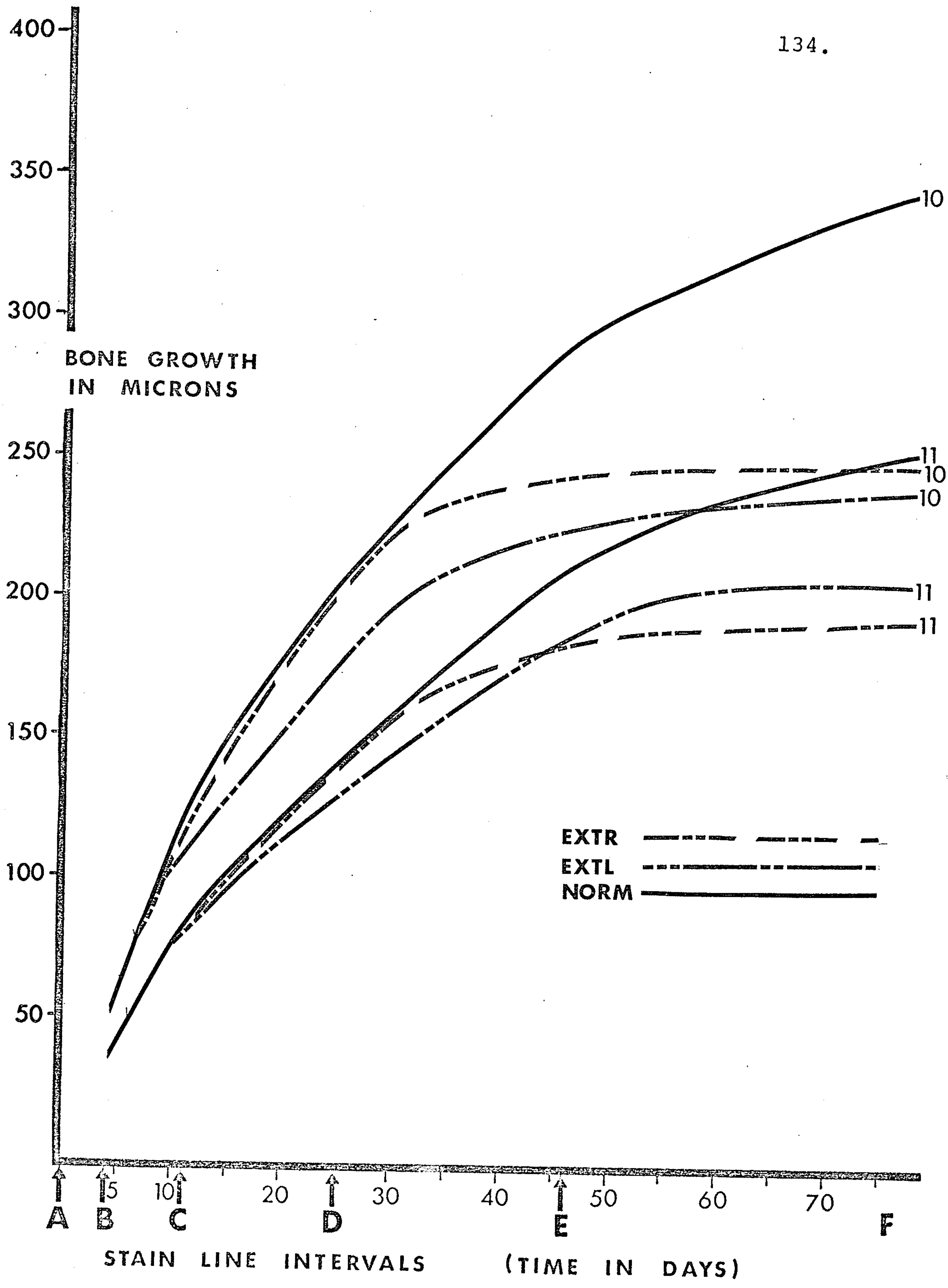


Figure 49. Dentin Formation of Extraction Adjusted for Age Difference.

TABLE XII

INCREMENTS OF DENTIN APPOSITION IN THE FIRST MOLAR

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
MANDIBLE SITE 10											
NORM	55	4	79	6	82	5	87	12	50	0	380
MASR	25	2	66	6	67	6	96	9	29	11	327
MASL	32	4	77	11	47	4	77	9	20	12	283
SHAR	44	5	69	5	97	6	83	14	22	13	358
SHAL	40	4	55	7	79	11	71	13	15	5	300
EXTR	39	8	47	8	73	17	15	8	0	0	215
EXTL	30	3	33	4	69	9	27	11	8	4	198
MANDIBLE SITE 11											
NORM	36	2	52	4	57	5	75	7	40	0	278
MASL	21	1	50	3	46	4	76	6	15	7	229
MASR	27	3	43	5	60	9	72	6	17	7	249
SHAR	28	3	44	3	66	6	56	10	23	12	251
SHAL	28	3	44	4	65	7	61	7	24	10	253
EXTR	28	3	34	2	55	4	26	7	4	4	167
EXTL	29	4	27	4	55	5	43	7	6	3	183

Significant side differences were determined at Site 10. The unoperated side of the masseterectomy group showed less dentin formation during the CD interval (P = .01). The sham and extraction groups manifested the same decline during the BC interval (P = .05). Overall assessment revealed more dentin formation on the operated side at Site 10 and the opposite situation at Site 11 for all experimental groups. These net side differences, however, were not statistically significant.

Unilateral extraction of the maxillary molars was therefore associated with markedly less dentin formation in the mandibular first molars of both sites. It would seem that such adjustments in dentin formation are mediated by mechanisms which act bilaterally, although the side differences that have been mentioned suggest a capibility of sophisticated individual adjustments dependent on local factors such as occlusion or non-occlusion and the direction of applied stress.

BUCCAL SURFACE

Three sites in the Post Symphyseal Region were located on the buccal surface of the mandible (Figure 50). They are numbered 7, 8 and 9 progressing from the inferior to the superior position. This progression was associated with decreasing amounts of bone growth as seen in comparison of values in Table XIII. Vertical development occurred more rapidly than growth in width in the Post Symphyseal Region. The relationship also held true for Sites 14, 15 and 17 in the First Molar Region which were analogous in position with Sites 7, 8 and 9, respectively.

The parallel pattern of stain lines and the limited amount of shape alteration (vertical development) with age of the Post Symphyseal Region indicated that this region was undergoing the least amount of anteroposterior relocation of all the mandibular regions studied. It was interesting to note that this region was cut in the area of the mental foramen. The comparative findings that height gain was progressing more rapidly than the increase in width would reflect the mode of enlargement of the cross-section of the lower incisor. The lower incisor occupied the major portion of this region and was likely a dominant factor in the determination of its mode of development.

Results for Site 7 served to assess the rate of

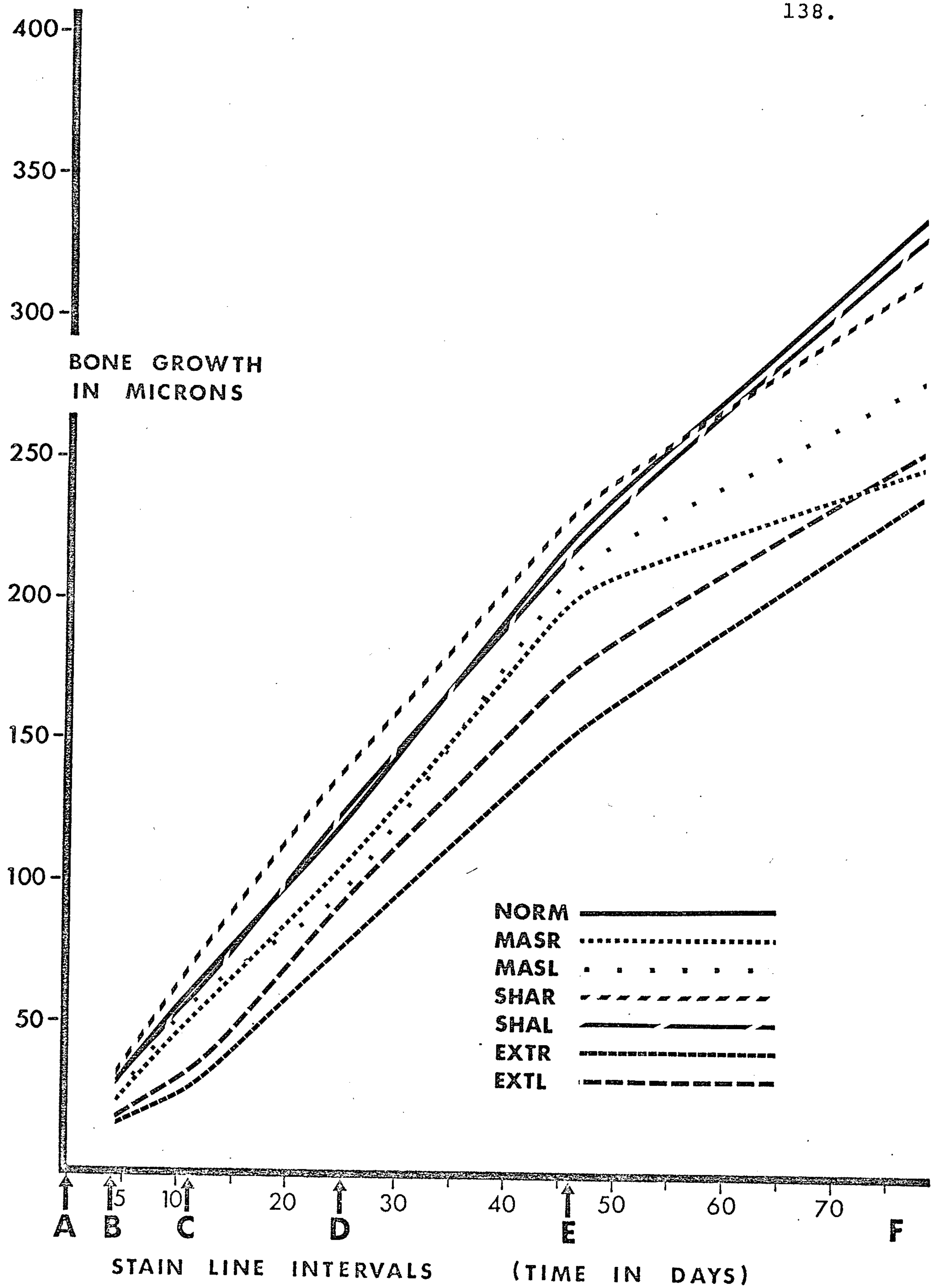


Figure 50. Cumulative Bone Growth at Mandible Site 9.

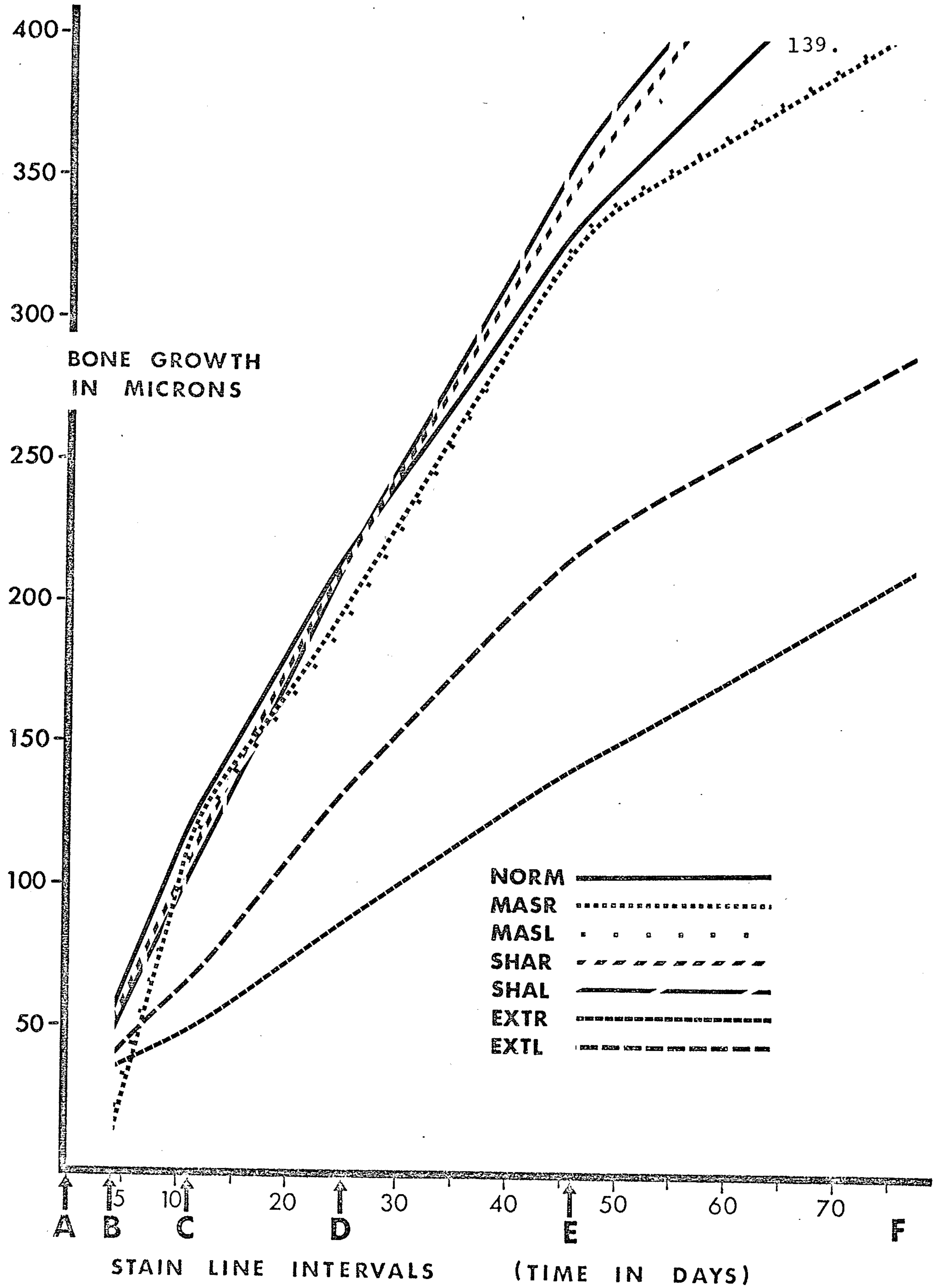


Figure 51. Cumulative Bone Growth at Mandible Site 15.

TABLE XIII

INCREMENTS OF BONE APPOSITION AT THE BUCCAL SURFACE

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
MANDIBLE SITE 7											
NORM	123	11	34	18	72	8	204	16	175	42	8
MASR	-	-	-	-	116	12	276	18	124	26	-
MASL	-	-	-	-	100	9	277	24	116	20	-
SHAR	60	0	130	40	191	42	243	26	172	23	796
SHAL	65	0	135	0	197	57	258	31	195	23	850
EXTR	-	-	50	0	88	18	175	25	152	38	-
EXTL	-	-	-	-	128	30	196	48	139	24	-
MANDIBLE SITE 8											
NORM	59	3	72	6	110	5	162	10	141	8	544
MASR	31	3	73	7	89	8	165	17	67	13	425
MASL	25	3	94	6	89	6	161	16	79	16	448
SHAR	53	4	70	9	111	13	150	10	151	11	535
SHAL	41	2	53	5	115	8	151	9	148	23	508
EXTR	41	3	38	5	105	12	118	12	104	15	406
EXTL	48	3	49	5	102	10	123	11	100	8	422
MANDIBLE SITE 9											
NORM	30	2	36	3	63	5	105	7	114	8	348
MASR	22	3	33	6	57	6	100	10	41	11	253
MASL	23	4	38	5	48	5	115	14	57	14	281
SHAR	33	3	43	4	71	11	95	8	75	12	317
SHAL	30	3	34	5	67	7	99	9	100	15	330
EXTR	17	4	10	3	54	11	80	8	75	9	236
EXTL	18	2	16	2	65	3	85	4	71	7	255
MANDIBLE SITE 15											
NORM	57	3	71	6	92	6	122	8	109	10	451
MASR	20	3	105	5	76	4	137	11	68	11	406
MASL	17	2	101	9	80	5	143	12	65	15	406
SHAR	53	4	60	4	107	12	137	13	140	15	497
SHAL	51	4	56	3	114	9	148	11	131	11	500
EXTR	36	3	13	3	39	3	57	6	63	6	208
EXTL	41	5	28	4	68	5	89	9	61	6	287

inferior drift of the lower incisor. The initial stain lines had been resorbed by the end of the experimental period so that only the CD, DE and EF intervals were available for comparisons. All experimental groups manifested more than normal apposition during the CD interval. The increase was significant only for the sham group (P = .01), but was continued into the DE interval by the masseterectomy group (P = .05). No significant differences were recorded during the EF interval although the normal group demonstrated the most apposition. Net growth of the extraction group was close to normal for these intervals. The single side difference was recorded for the slower growing operated side of the sham group during the EF interval (P = .01). It would seem that the muscle surgery groups experienced greater inferior drift (eruption) of the lower incisor. However, these findings may have occurred as compensation for extreme retardation of incisor development in the earlier intervals since inspection of the gross specimens revealed a reduction in incisor size and development (amount of curvature) in the masseterectomy group.

Site 8 growth curves illustrated the common altered growth patterns for each group and did not seem subject to unique influence. The normal significant intervals were observed. Early retardations, found in all experimental groups, would indicate a similar history for the neighboring

Site 7. Significant side differences added further support to the possibility of an immediate effect on growth in this area for the sham and masseterectomy groups. The operated side of the masseterectomy animals grew less in the BC interval ($P < .05$). In contrast, the operated side of the sham group grew more during AB and BC intervals ($P < .01$ and $P < .05$).

Site 9 observations produced the same growth curve configurations as those for Site 8 (Figure 50) although the amount of apposition was considerably less.

Growth at Site 15 in the First Molar Region was seen to be affected by specific influences in the case of the extraction group. The operated side grew much less than normal throughout the entire experimental period ($P = .01$). The unoperated side also grew less than normal but the degree of significance of this finding was modified to the 5 per cent level during the CD and DE intervals. The side differences that occurred because of less growth of the operated side were very significant ($P \ll .01$) during the BC, CD and DE intervals as well as for the total growth.

The depressed growth rate was demonstrated only for the extraction group and was significantly different from that of the masseterectomy and sham rates ($P = .01$). The depression of extraction group growth was a generalized finding at most sites located in the First Molar Region and was thought to be directly related to the maxillary molar extractions. The resultant alteration in functional stress was likely a dominant factor in the "atrophic" condition of the mandibular sites.

CRANIUM

The detailed patterns of accelerations and decelerations in growth rate as compared to normal values throughout the course of the experimental period have been reported for experimental groups in connection with growth at the thirty sites in the mandible. It was demonstrated that a typical growth curve pattern existed for each group and that these patterns were found at the majority of sites albeit the significance of their differences from normal may vary somewhat. Such were the generalized findings. Sites of particular interest, such as the masseter muscle attachments and the alveolar regions, demonstrated specific growth curve patterns that were interpreted to be due to the particular surgical intervention. The fifty-eight sites studied in the rat cranium also reflected the same type of growth curve patterns. Since the individual accelerations and decelerations that occur during certain growth intervals have been demonstrated for the mandible, the findings reported for cranial growth sites will be mainly concerned with the overall effect or net growth of the groups at each site. Important increment deviations will be presented in support of the assessments made of the overall effect.

DORSUM OF THE NASAL CAVITY

The rat, a long snouted mammal, experiences a large component of anteroposterior growth of the nasal bone, both by growth in the frontonasal suture and by endochondral bone formation at the anterior end (Schour and Massler, 1951; Cleall, 1968). The study of growth in the coronal plane also revealed substantial growth increments. The dorsal surface of the nasal bones was appositional while the ventral surface was resorptive. Sites 4 and 5 in the Incisor Region, 11 and 12 in the Premaxillary Region and 21 in the Malar Process Region provided assessment of the dorsal drift of the nasal bones.

More deposition was recorded at the lateral sites (4 and 11) than at the medial sites (5 and 12) as shown in Table XIV. The proportional distinction of this finding was much greater in the Premaxillary Region. In addition, the amount of total growth was seen to increase from anterior to posterior regions. These growth differences were in accordance with the gross morphology of the regions in question and the translation of the nasal bones that occurs with growth (Baer, 1954) resulting in flattening of the dorsal surface of the cranium with age as viewed from the lateral aspect (as well as in coronal section).

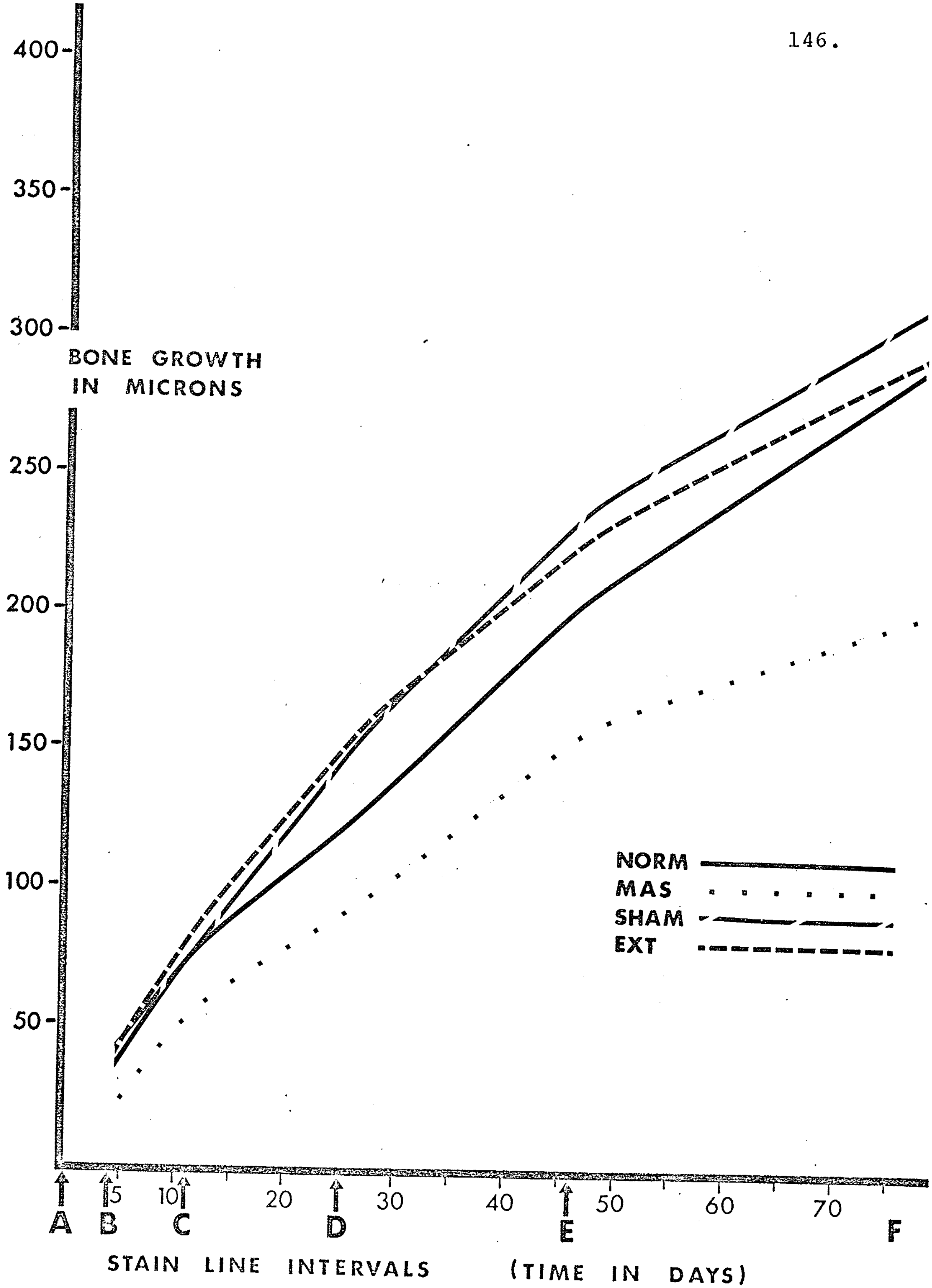


Figure 52. Cumulative Bone Apposition at Cranium Site 4.

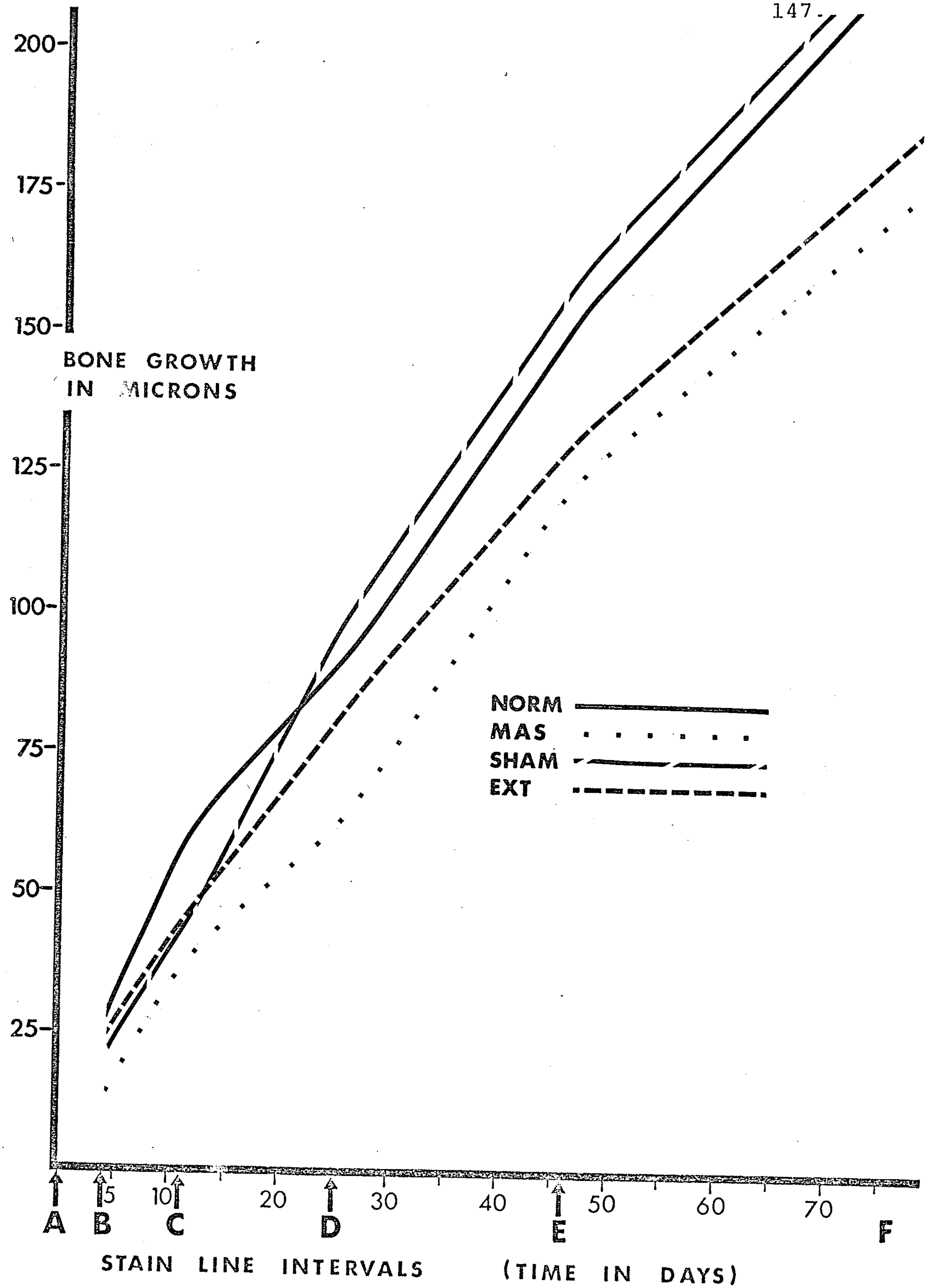


Figure 53. Cumulative Bone Apposition at Granium Site 5.

TABLE XIV

INCREMENTS OF BONE APPOSITION ON THE DORSUM OF THE NASAL CAVITY

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 4											
NORM	37	4	43	2	48	5	85	5	73	7	286
MASR	19	4	38	4	39	3	67	7	34	6	197
MASL	22	5	36	4	30	6	65	7	45	12	198
SHAR	46	6	31	3	73	5	94	9	64	11	308
SHAL	38	5	41	4	71	6	88	5	63	12	301
EXTR	43	5	50	8	73	13	78	7	54	11	298
EXTL	42	6	32	4	65	4	76	7	60	6	275
CRANIUM SITE 5											
NORM	28	4	32	3	34	3	60	5	59	8	213
MASR	13	2	23	1	25	3	63	6	49	7	173
MASL	13	2	26	4	24	2	63	4	46	7	172
SHAR	19	1	23	2	56	5	68	6	59	7	225
SHAL	22	2	22	3	56	6	59	5	59	5	218
EXTR	24	3	20	1	38	4	50	4	49	5	181
EXTL	24	2	18	1	42	6	49	5	52	6	185
CRANIUM SITE 11											
NORM	61	8	74	5	84	5	125	7	131	13	475
MASR	22	3	93	9	84	7	164	9	76	15	439
MASL	23	3	103	10	83	10	182	20	59	12	450
SHAR	53	5	59	5	139	17	179	12	134	7	564
SHAL	51	2	67	9	142	20	173	15	119	10	552
EXTR	54	5	48	5	105	11	131	7	111	13	449
EXTL	67	7	55	7	111	13	119	3	98	9	450
CRANIUM SITE 12											
NORM	31	5	42	3	53	5	104	6	102	8	332
MASR	14	2	31	2	39	5	113	10	59	11	256
MASL	15	2	33	2	37	5	104	10	65	11	254
SHAR	25	2	30	4	77	8	132	11	127	14	391
SHAL	21	2	29	3	76	11	129	11	122	12	377
EXTR	36	4	38	6	69	7	121	13	104	7	368
EXTL	33	5	38	6	77	6	101	8	102	9	351

(Continued)

TABLE XIV (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 21						
NORM	31	4	45	5	64	8	122	8	126	13	388
MASR	16	1	51	18	66	12	131	25	53	7	317
MASL	14	1	44	12	82	40	153	18	89	31	382
SHAR	35	15	10	20	61	13	96	14	108	9	310
SHAL	27	7	33	0	50	11	94	7	116	13	320
EXTR	30	0	25	0	74	10	109	12	85	6	323
EXTL	45	0	35	15	71	9	97	12	91	10	339
					CRANIUM SITE 26						
NORM	33	6	43	8	99	13	155	10	140	16	470
MASR	13	1	66	11	57	10	178	18	61	15	375
MASL	23	8	60	9	49	7	180	18	68	19	380
SHAR	31	5	25	4	101	23	141	24	119	24	417
SHAL	32	6	27	3	97	21	158	21	115	23	429
EXTR	42	6	23	4	106	19	85	9	67	9	323
EXTL	33	5	22	2	90	17	90	15	59	8	294

Experimental Groups. The growth rate curves of the experimental groups illustrated the usual configurations (Figures 52 and 53). Sham and extraction animals achieved normal growth at Site 4 due to an increased rate during the CD interval (P = .05). The masseterectomy animals were most affected and their curves manifested the customary relation to the normal. Growth at Site 5 also involved no side differences. This important finding was common to most nasal cavity sites and discredited the possibility of the development of asymmetry by differential bone deposition. The curve pattern shown for Site 5 was a good example of the modal configurations. The growth of masseterectomy and extraction groups was equally reduced.

In contrast, the total growth of these groups was in the range of normal at Site 11 while the sham group spurted during the CD and DE intervals (P = .01). The apparent growth stimulation of the sham group midway through the experimental period was an often repeated observation. Both extraction and sham groups achieved more than normal apposition at Site 12, although the increase was significant only for the sham animals (P = .05 during CD and DE). The masseterectomy group was subject to initial and final decelerations (P = .01) and consequently grew less than all other groups (P = .01).

From these observations on nasal bone development, it was concluded that the respective surgical procedures had little effect on growth of the extraction group; stimulated sham group apposition and effected a significant decrease in deposition for the masseterectomy group.

Only the operated side of the masseterectomy animals evidenced a significant growth difference at Site 21. The EF interval rate was less than normal (P = .01).

The frontal bone surface measured at Site 26 represented the posterior end of the nasal capsule and was located in the First Molar Region. The extraction demonstrated a decrease in the total amount of apposition which was due to an accentuation of the usual extraction curve pattern. The BC interval decrease was significant at the 5 per cent level and the DE and EF interval decreases were significant at the 1 per cent level. Other sites in the First Molar Region of the extraction group, that were not involved in healing accomodation, also showed the effect of molar extraction on growth in this cross-section.

NASAL CAVITY

When added to the dorsal surface findings, the array of growth curves presented in Figures 54 to 58 presents the diversity of apposition rates and group interactions that could be found all in one coronal section; the Malar Process Region. These sites can be located as perimeter locations in Figure 17. Site 8 from the Premaxillary Region and Site 24 from the First Molar Region have also been included in this classification. The occurrences at other sites in these regions are described under more particular headings.

Site 8, a palatal location, was subject to very significant (P = .01) declines in bone apposition during the AB and BC intervals for all experimental groups. This lessened rate continued to be significant during the CD and EF intervals for the masseterectomy (the most affected) group. No side differences of any account were demonstrable.

Sites 14 and 15 showed more growth but were also palatally located. They shared the pattern of early growth depression with Site 8. The masseterectomy manifested the identical behavior at Sites 8 and 14. The most affected group at Site 15, however, were the extraction animals (Table XV). Notable side differences (P = .01) were recorded as the operated side grew much less than the unoperated at both Sites 14 and 15. Unilateral molar

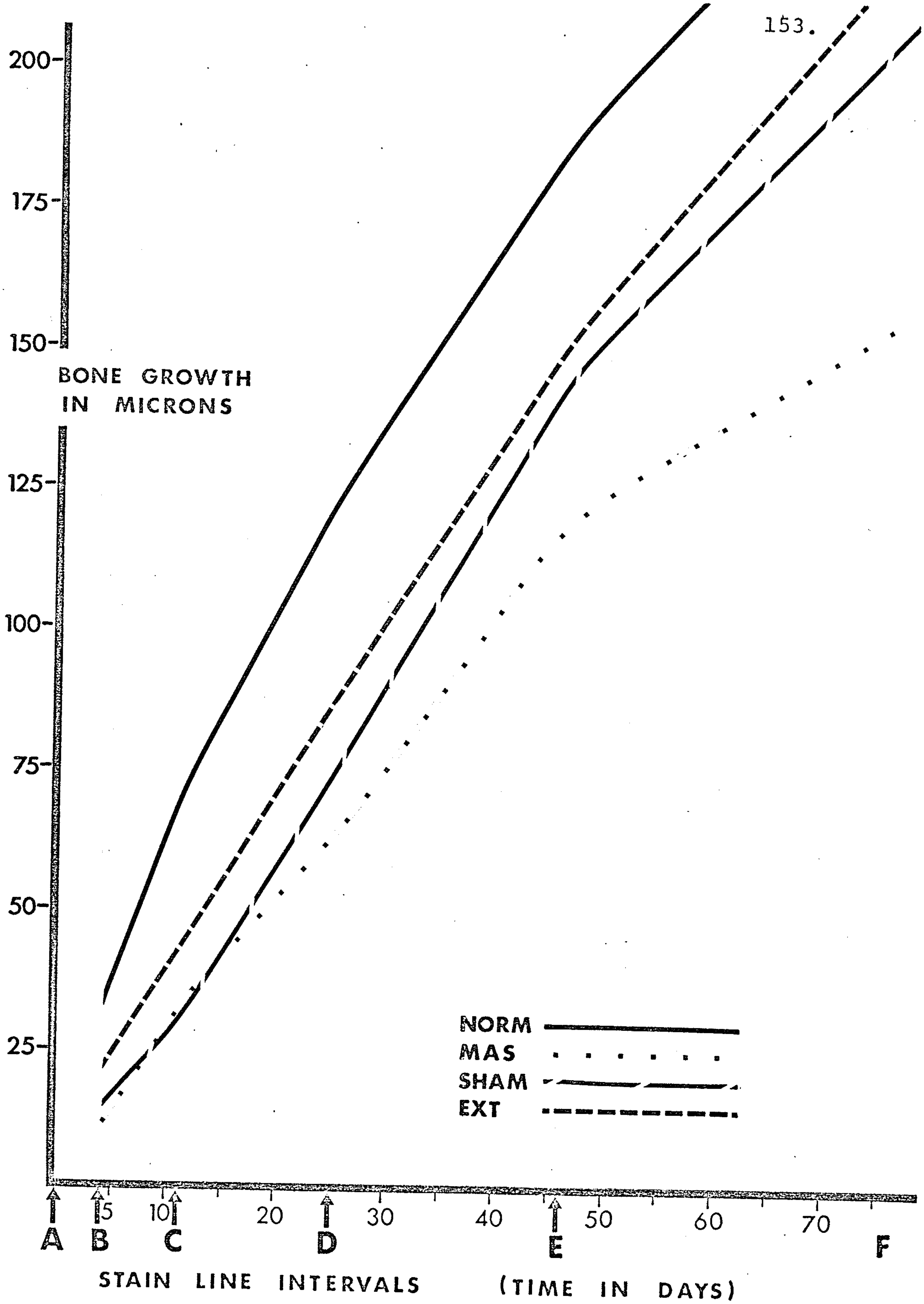


Figure 54. Cumulative Bone Apposition at Cranium Site 8.

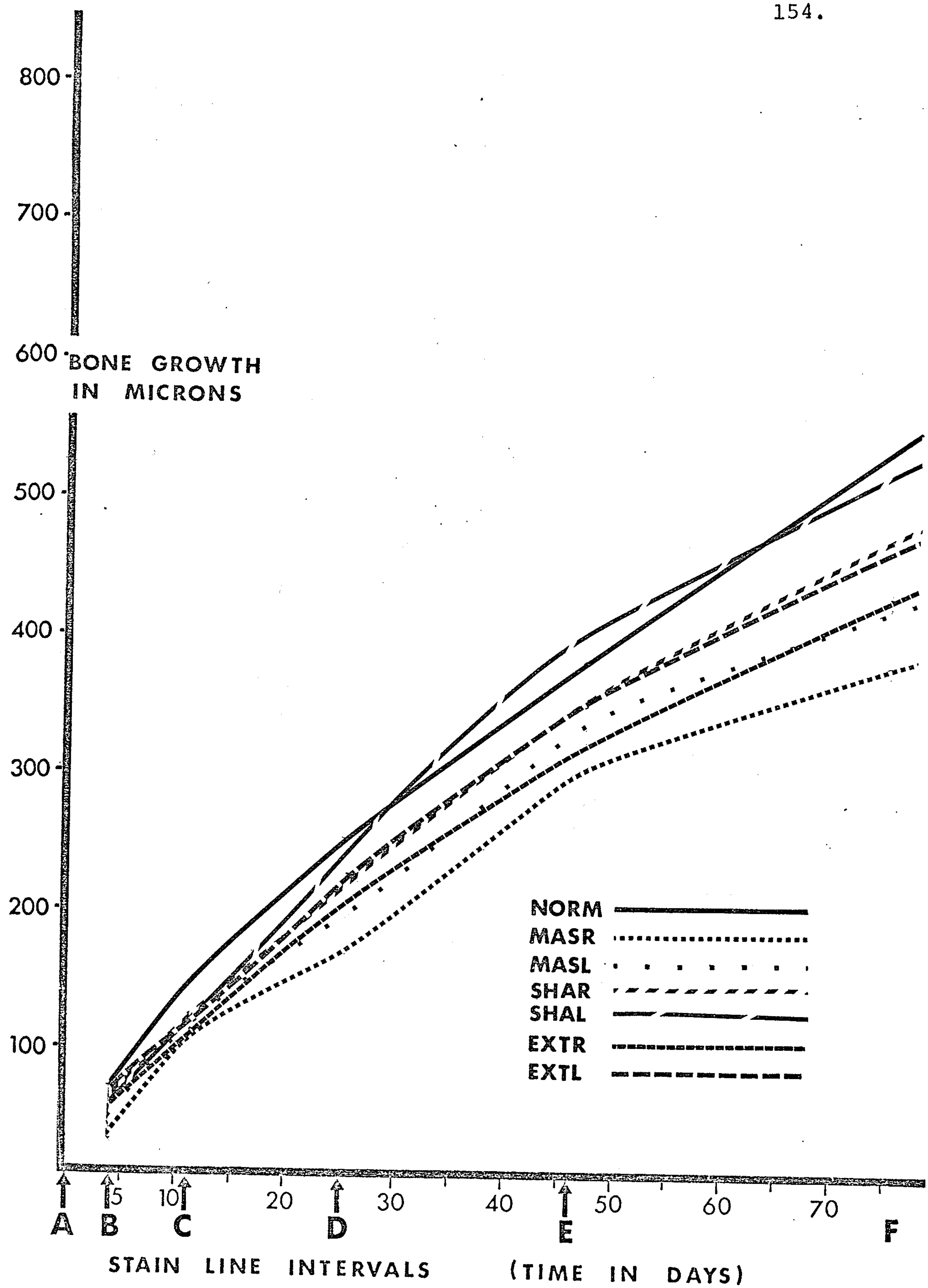


Figure 55. Cumulative Bone Apposition at Cranium Site 14.

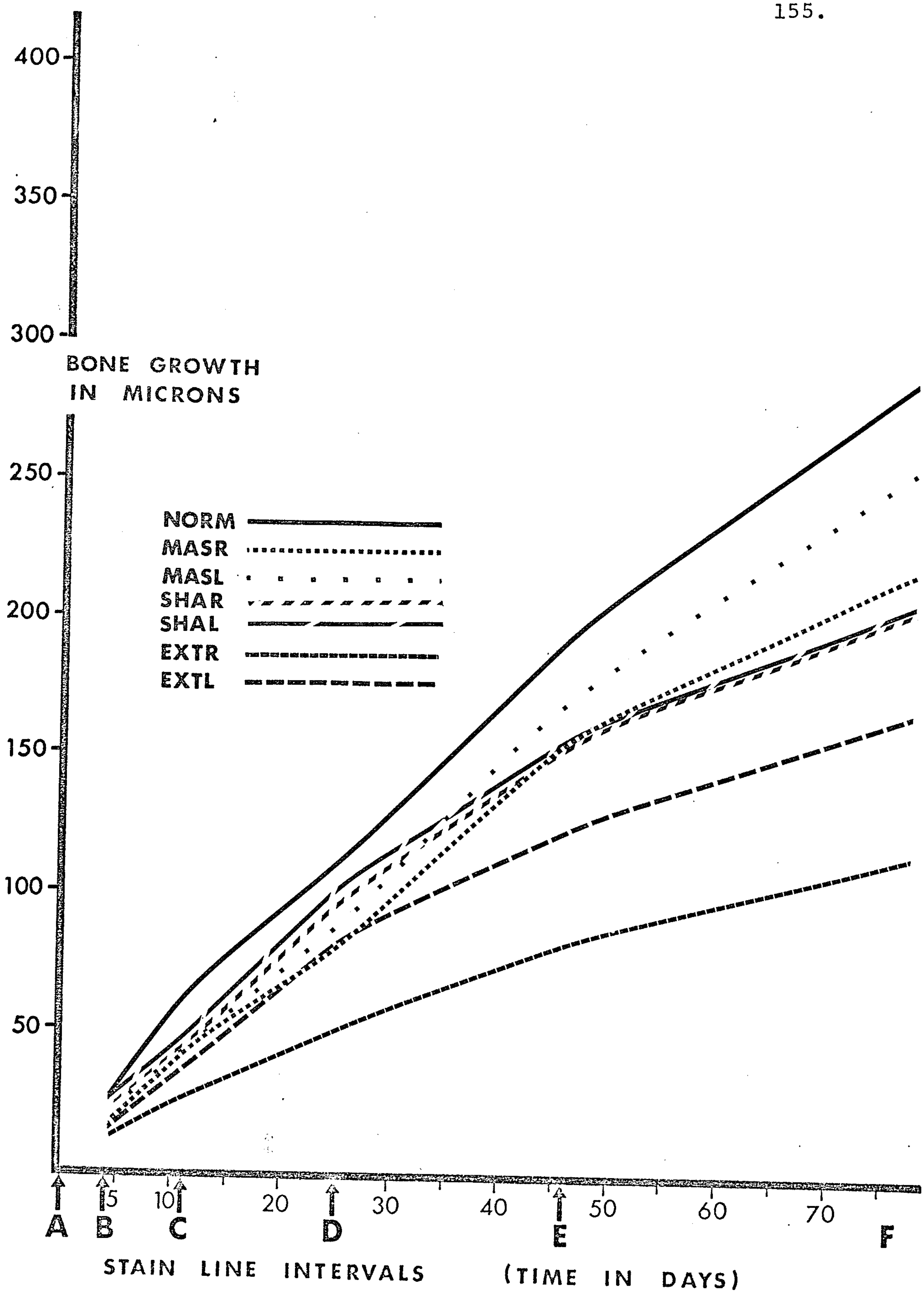


Figure 56. Cumulative Bone Apposition at Cranium Site 15.

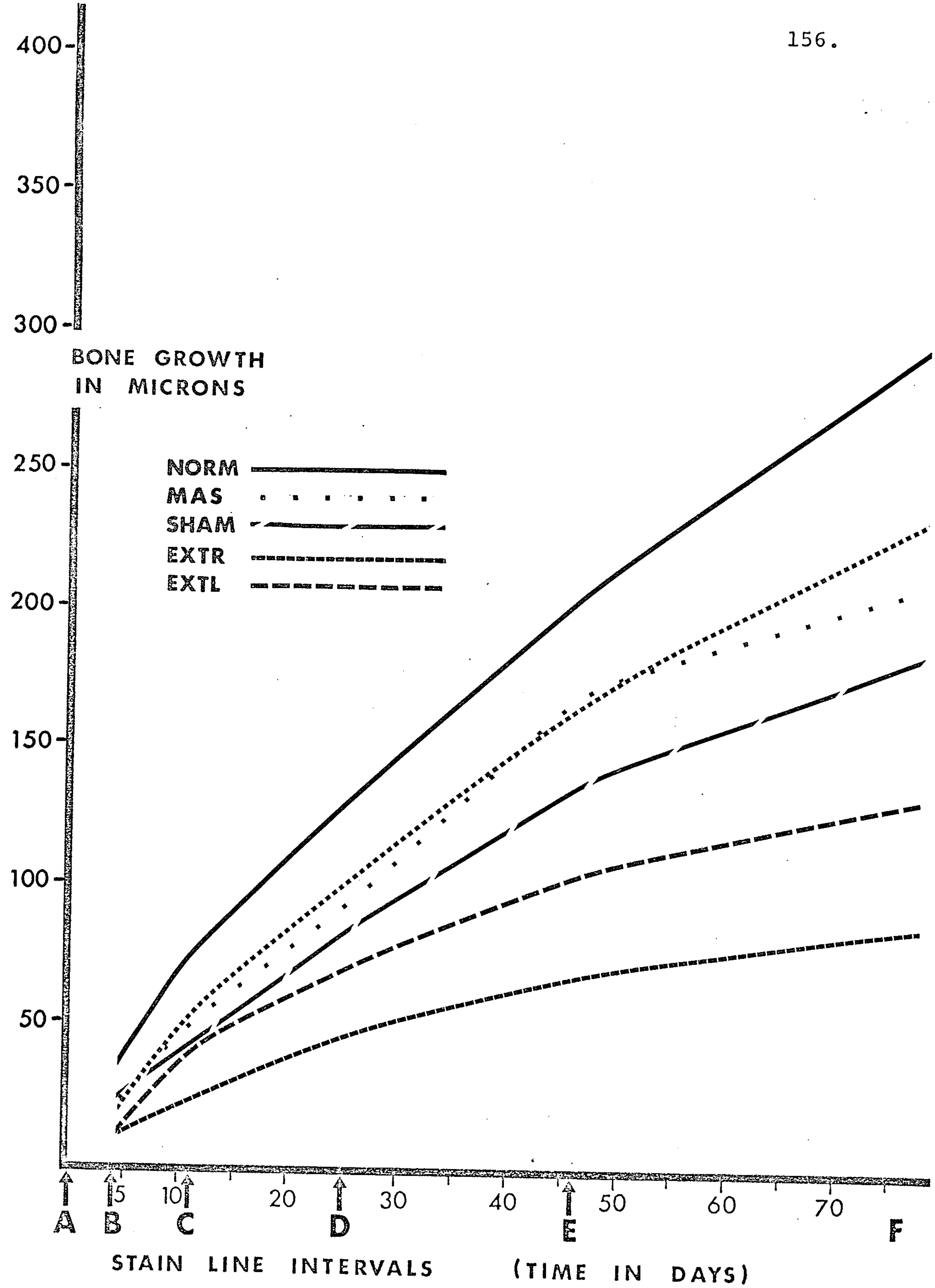


Figure 57. Cumulative Bone Apposition at Cranium Site 16.

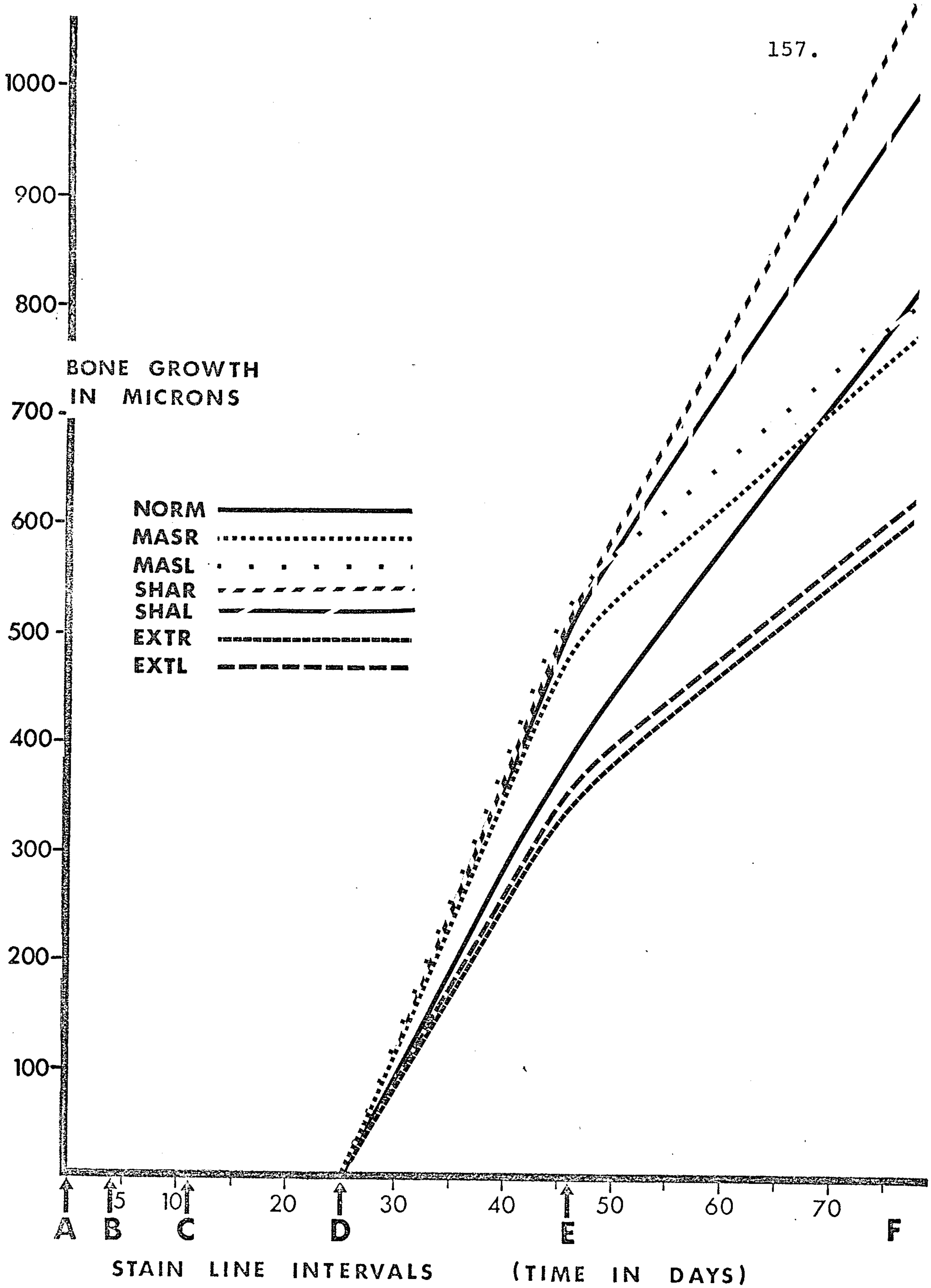


Figure 58. Cumulative Bone Apposition at Cranium Site 18.

TABLE XV

INCREMENTS OF BONE APPOSITION AROUND THE NASAL CAVITY

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 8											
NORM	31	3	39	3	55	5	65	4	64	7	254
MASR	10	1	22	3	29	4	61	5	29	11	151
MASL	9	1	23	3	34	4	55	6	38	10	159
SHAR	12	2	17	3	44	6	79	8	48	21	200
SHAL	13	2	16	2	48	7	67	7	67	9	211
EXTR	20	4	22	3	43	3	66	1	68	4	219
EXTL	20	1	23	2	49	4	66	5	66	6	224
CRANIUM SITE 14											
NORM	54	5	82	4	104	5	142	17	142	12	524
MASR	23	4	73	8	62	5	135	10	73	12	366
MASL	32	6	76	11	74	9	147	8	76	11	405
SHAR	48	3	62	6	94	7	134	11	117	13	455
SHAL	47	3	64	4	119	17	157	14	121	12	508
EXTR	45	4	53	4	94	6	111	10	112	10	415
EXTL	51	6	51	5	109	6	127	6	110	7	448
CRANIUM SITE 15											
NORM	25	2	38	2	47	4	82	6	82	5	274
MASR	18	4	26	3	40	6	77	4	56	10	217
MASL	22	3	23	1	46	6	86	8	53	8	230
SHAR	22	1	24	2	53	6	59	8	43	8	201
SHAL	26	2	27	3	52	4	56	5	43	7	204
EXTR	13	2	15	4	26	4	31	8	29	7	114
EXTL	17	2	21	2	45	6	42	4	39	5	164
CRANIUM SITE 16											
NORM	34	2	42	3	51	5	76	6	76	6	279
MASR	24	6	34	4	46	8	66	6	41	6	211
MASL	23	4	29	4	44	7	72	11	41	8	209
SHAR	25	3	20	3	41	5	57	9	33	4	176
SHAL	23	2	21	4	41	5	52	7	54	7	191
EXTR	11	3	13	4	23	7	22	7	17	5	86
EXTL	14	2	29	9	30	4	34	3	25	5	132

(Continued)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 18						
NORM	93	23	178	21	275	51	401	35	385	37	1332
MASR	0	0	0	0	0	0	492	32	250	66	-
MASL	0	0	0	0	0	0	538	48	235	56	-
SHAR	0	0	0	0	550	0	525	37	501	81	-
SHAL	0	0	0	0	650	0	517	38	428	48	-
EXTR	0	0	0	0	0	0	345	30	228	21	-
EXTL	0	0	0	0	300	0	363	20	236	20	-
					CRANIUM SITE 19						
NORM	26	14	57	6	108	24	252	16	298	31	741
MASR	0	0	0	0	0	0	291	29	116	28	-
MASL	15	0	60	0	35	0	272	28	107	22	489
SHAR	0	0	0	0	350	0	223	16	251	10	-
SHAL	80	0	25	0	205	170	220	24	273	13	803
EXTR	20	0	20	0	126	24	207	24	173	25	546
EXTL	35	0	35	0	135	21	198	17	146	11	549
					CRANIUM SITE 24						
NORM	36	11	34	4	70	10	88	6	100	8	328
MASR	15	5	23	8	33	8	92	9	56	8	219
MASL	17	3	23	3	32	2	90	11	58	6	220
SHAR	20	2	24	4	58	7	95	13	104	18	301
SHAL	20	2	25	6	56	8	90	10	87	19	278
EXTR	15	3	33	2	64	24	76	10	83	7	271
EXTL	28	6	42	5	61	8	73	3	90	16	294

extraction no doubt had a direct effect in this area.

The overall behavior of sham group appositional activity yielded less growth than normal. The pattern of increments was different for sham and masseterectomy groups.

The similarity in bone growth occurrences at Sites 15 and 16 was due to relatively parallel amounts of deposition along the lateral wall of the cranium.

In the First Molar Region, Site 24 was located on the lateral wall in a position analogous to that of Sites 15 and 16. Intranasal resorption decreased the number of animals in which measurement representing the entire study period could be made. The differences between groups were therefore not significant except in the EF interval where the masseterectomy group grew less than the normal and sham groups ($P = .05$). The irregularity of the normal curve was due to the cross-sectional nature of mean increment establishment.

Resorption on the intranasal surface eliminated the early stain lines at Site 18. Only DE and EF intervals could be compared as shown in Figure 58. Alterations during the DE interval were not significant although the muscle surgery (sham and masseterectomy) groups grew faster than normal while the extraction group grew slower. During the EF interval, the sham group continued its stimulated growth

(P = .05), but the masseterectomy and extraction groups both manifested rate deceleration (P = .01). Stimulated growth in muscle surgery groups near areas of surgical intervention was also observed at other sites in the cranium and mandible.

The occurrences at Site 17, classified as a muscle attachment (Figure 69 and Table XIX, pages 183-185), should be compared to the final intervals recorded at Site 18 to place the graphical view of Site 18 into perspective. The masseterectomy and extraction group rates bore the same relation to normal during DE and EF intervals at both sites. The sham group did not demonstrate greater than normal growth at Site 17.

To complete the observations around this section, Site 19 was examined. Again intranasal resorption has removed the early stain lines but the identical relationships during the DE and EF intervals were found as existed at Site 18. No important side differences were revealed at Sites 17, 18 or 19.

CRANIAL VAULT

The pairs of ectocranial and endocranial sites were measured to assess growth of the cranial vault. These sites were located midway between the sagittal suture and the temporal ridge in the Zygomatic (35 and 36), Squama Temporal (47 and 48), and Tympanic Bulla Regions (56 and 57). Reference to the site diagrams and sectioning chart will clarify the anteroposterior relationship of these sites.

The independent behavior of ectocranial and endocranial bone surfaces was manifested for these sites as it was for the temporal ridge locations. The ectocranial surface of the normal group always grew more than the endocranial surface for the cranial vault sites as disclosed in Table XVI. The opposite relationship held for the experimental groups. The ectocranial surfaces grew less than the endocranial surfaces in accord with the gradual "flattening" of the cranial vault that is observed with age. The growth difference between surfaces was most pronounced in the Zygomatic Region (frontal bone) and the Tympanic Bulla Region (posterior end of parietal bone) where the curvature was also most pronounced. On further comparison, it was seen that the ectocranial to endocranial differences in normal growth increments formed a more complicated pattern with respect to increasing age. The

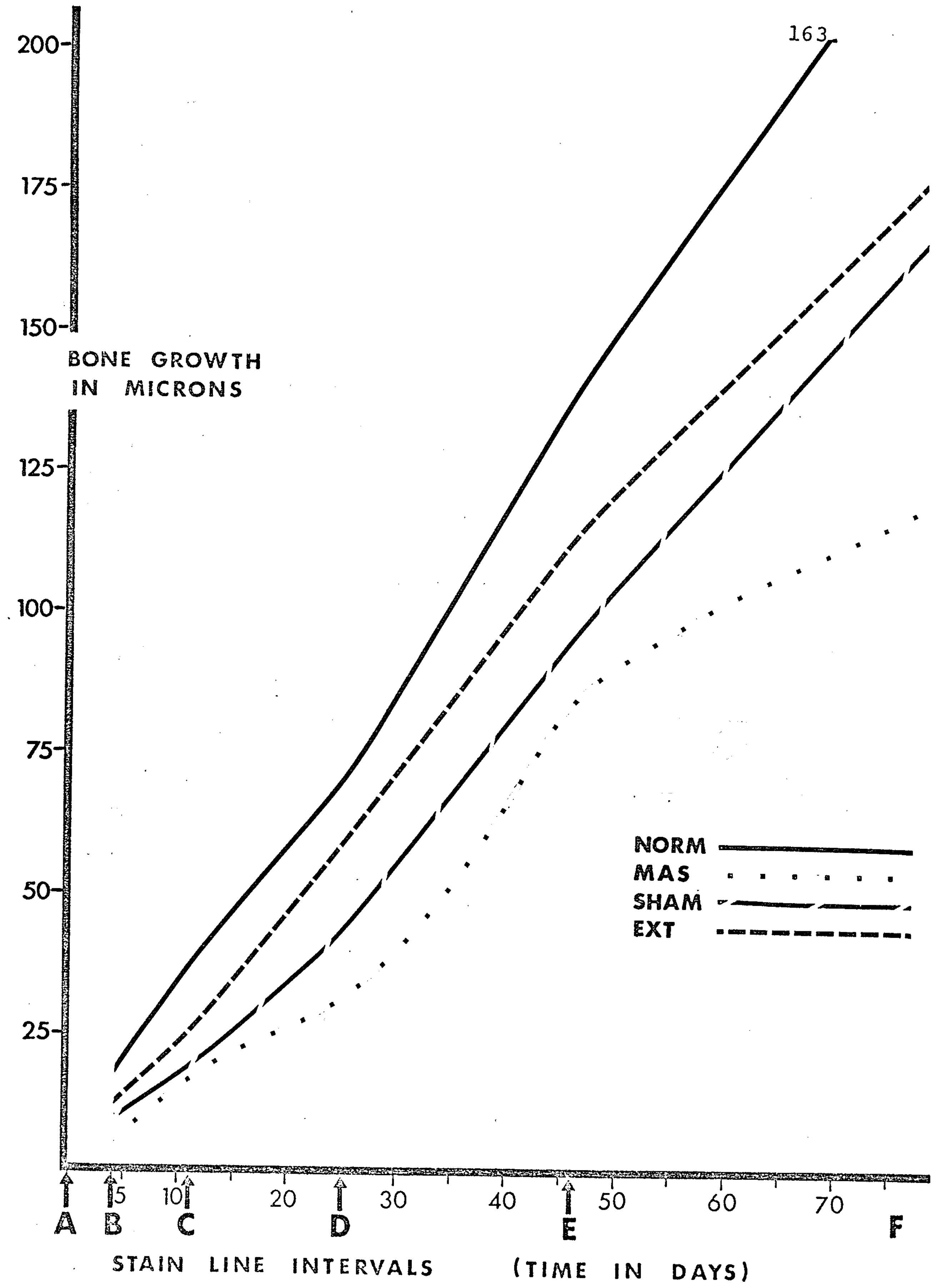


Figure 59. Cumulative Bone Apposition at Cranium Site 35.

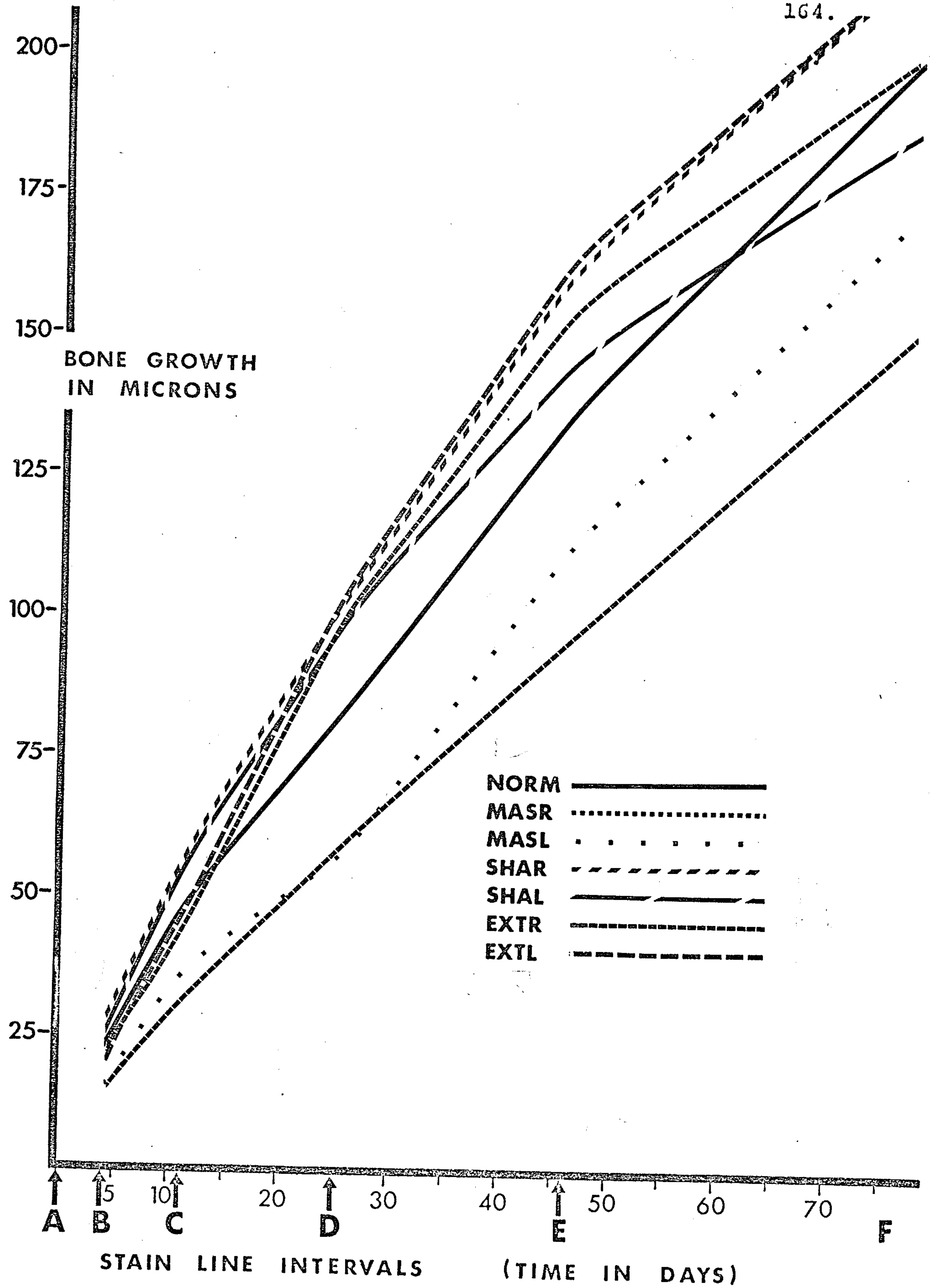


Figure 60. Cumulative Bone Apposition at Cranium Site 36.

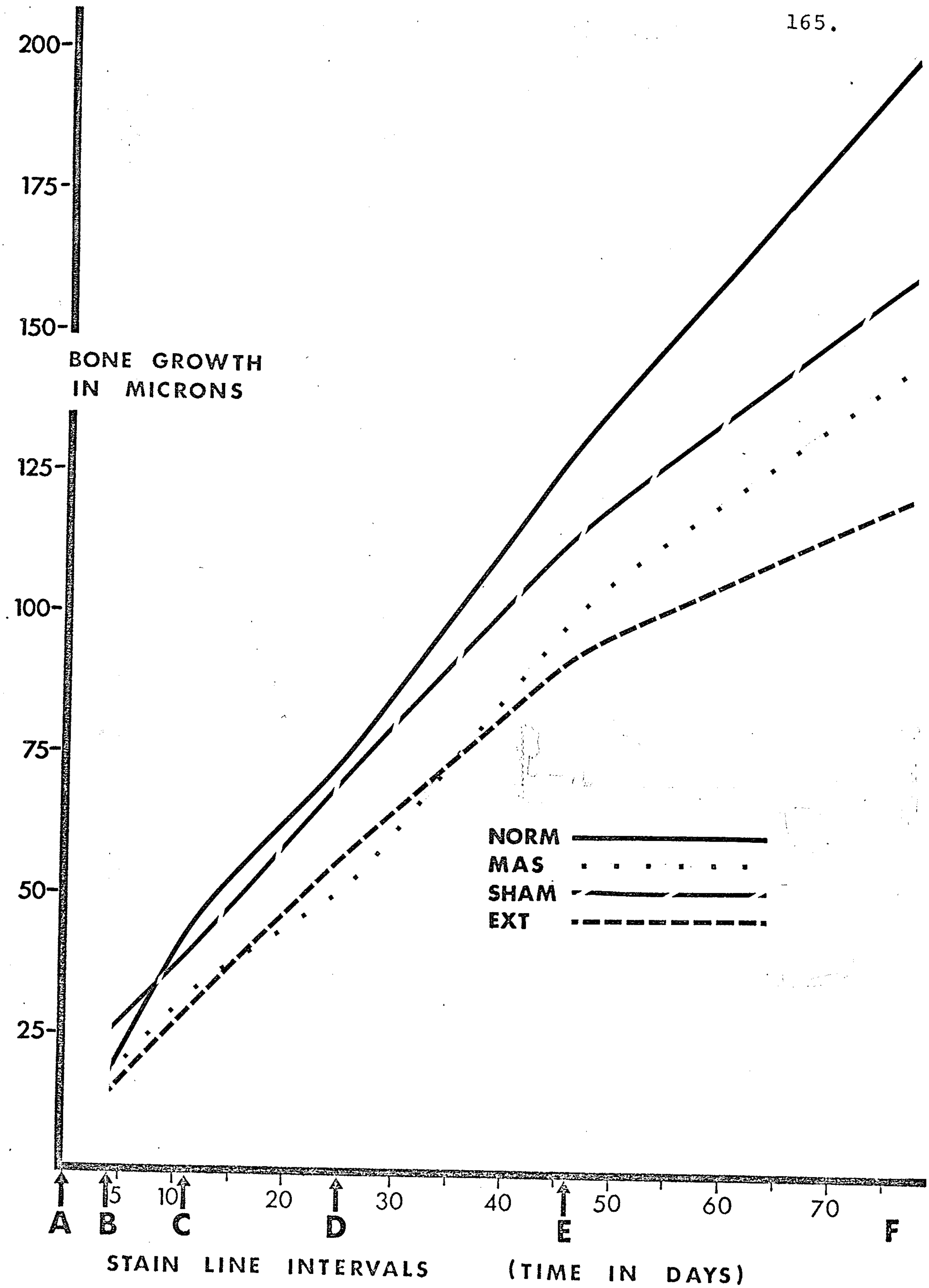


Figure 61. Cumulative Bone Apposition at Cranium Site 56.

TABLE XVI

INCREMENTS OF BONE APPOSITION AT THE CRANIAL VAULT

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 35											
NORM	16	2	19	2	36	3	73	5	81	6	225
MASR	5	0	12	3	21	7	51	8	34	9	123
MASL	5	1	11	3	12	2	55	3	33	8	116
SHAR	9	2	8	1	25	5	59	10	59	8	160
SHAL	8	2	10	2	26	4	52	5	68	9	164
EXTR	11	2	11	2	34	6	56	4	56	4	168
EXTL	13	2	14	3	36	6	61	5	57	5	181
CRANIUM SITE 36											
NORM	21	2	23	3	35	3	54	4	57	5	190
MASR	13	2	17	2	28	6	39	10	50	20	147
MASL	13	2	21	6	22	4	57	18	56	20	169
SHAR	26	6	29	7	47	9	62	8	52	9	216
SHAL	23	6	31	9	45	13	49	9	38	11	186
EXTR	20	3	23	3	56	11	58	7	41	6	198
EXTL	19	2	26	3	58	11	63	7	50	9	216
CRANIUM SITE 47											
NORM	12	1	16	1	27	2	51	3	69	5	175
MASR	6	1	11	2	11	2	41	5	23	5	92
MASL	7	1	10	3	11	3	38	6	30	7	96
SHAR	8	1	7	2	22	4	41	4	46	6	124
SHAL	10	1	5	1	20	4	34	5	42	5	111
EXTR	12	1	14	2	24	2	34	4	39	4	123
EXTL	8	1	12	2	28	3	37	3	38	3	123
CRANIUM SITE 48											
NORM	14	1	19	1	27	2	44	2	47	4	151
MASR	9	1	19	2	14	2	35	4	16	12	93
MASL	11	1	17	2	14	2	38	3	32	8	112
SHAR	15	2	16	2	27	4	42	3	36	3	136
SHAL	15	1	16	2	29	3	41	2	39	5	140
EXTR	14	2	16	1	27	2	39	3	35	3	131
EXTL	12	1	15	1	28	2	35	2	34	3	124

(Continued)

TABLE XVI (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 56						
NORM	18	1	26	2	28	2	59	6	61	6	192
MASR	16	2	16	1	18	3	47	5	41	10	138
MASL	17	1	13	2	19	3	54	7	41	13	144
SHAR	21	2	19	2	33	4	42	4	38	6	153
SHAL	27	6	10	7	29	5	48	5	41	5	155
EXTR	13	1	15	1	27	3	38	9	24	4	117
EXTL	14	1	15	1	29	3	35	5	27	3	120
					CRANIUM SITE 57						
NORM	15	2	16	2	29	4	60	5	84	6	204
MASR	8	3	10	2	13	1	43	6	34	7	108
MASL	5	0	8	3	22	8	45	8	28	10	108
SHAR	12	1	11	2	28	6	49	11	49	7	149
SHAL	13	1	11	2	25	5	57	8	58	11	164
EXTR	16	2	18	3	48	10	66	7	73	8	221
EXTL	14	2	16	3	39	8	63	9	59	9	191

endocranial surfaces did grow more than the ectocranial during the AB and BC intervals. The CD increment was equal for both surfaces, but then the DE and EF intervals revealed the dominating reversal of ectocranial surfaces growing more than endocranial. The trend thus described was credited to maturation changes as the flattening of the cranial vault bones, from their youthful curvature, neared completion. The implication of a delay in maturation, most marked in the masseterectomy group, existed since the experimental groups did not reflect the normal reversal until the EF period as determined from examination of Table XVI.

Growth curves for Sites 35 and 36 are presented in Figures 59 and 60 as representative of the configurations found for the cranial vault sites. Sham and extraction group comparisons showed no significant differences except at Site 56 (Figure 61) where the lessened deposition of the extraction group was due to an immediate rate decline during the AB interval (P = .01). All the experimental groups displayed their modal growth curves. The sham and experimental groups approximated normal growth more closely than the masseterectomy group which had the largest number of significantly smaller than normal (P = .01) increments. Again, Site 56 was the exception since the extraction group followed the fastest decline in apposition during the DE and EF intervals (P = .01).

The lack of any important side differences lends support to the view that the effects at sites not directly involved in surgical procedures are not specific for operated or unoperated sides.

TEMPORAL RIDGE

Normal Growth. The ectocranial and endocranial sites of measurement associated with the temporal ridge of the frontal and parietal bones displayed independent growth rate curve configurations. The ectocranial surface, which formed the substance of the ridge, grew increasingly faster with advancing age. The endocranial surface, however, developed in accordance with the usual finding of gradually decreasing increments. This comparison was also found valid for the experimental groups and is illustrated by Sites 45 and 46 in the Squama Temporal Region (Figures 62 and 63). Another major difference was observed when the amounts of bone apposition were compared (Table XVII). The ectocranial site grew 4 times more than the endocranial site in the Squama Temporal Region and 3.5 times as much in the Tympanic Bulla Region.

The greatest degree of development of the temporal ridge was recorded at the frontal bone for Site 34. An interesting acceleration of normal growth during the DE interval was followed by the usual slight deceleration in the later periods. The acceleration with age was also a feature of growth at Site 25 for the normal group. This was expected since Site 25 was located on the ectocranial surface of the frontal bone in the First Molar Region.

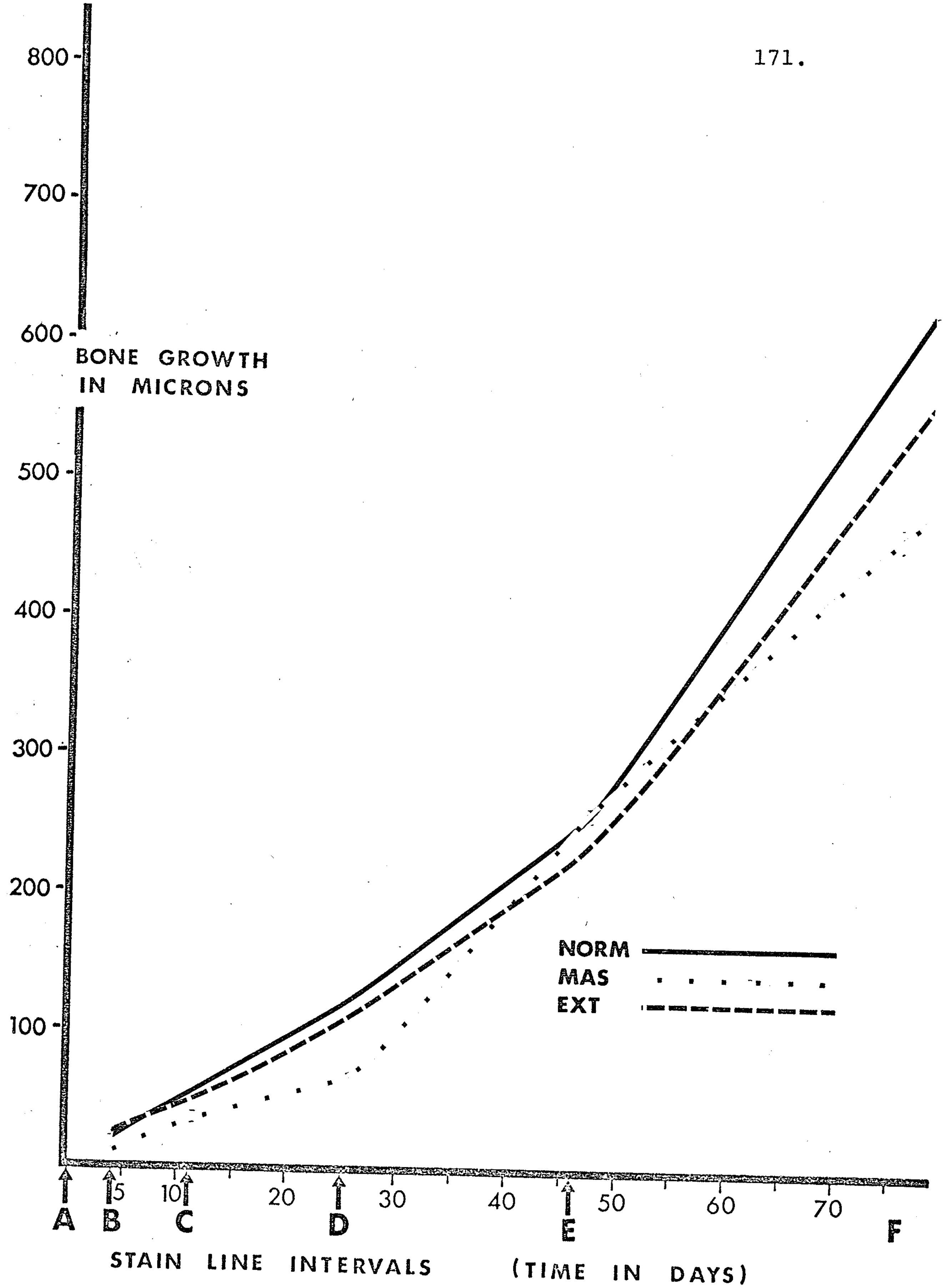


Figure 62. Cumulative Bone Apposition at Cranium Site 45.

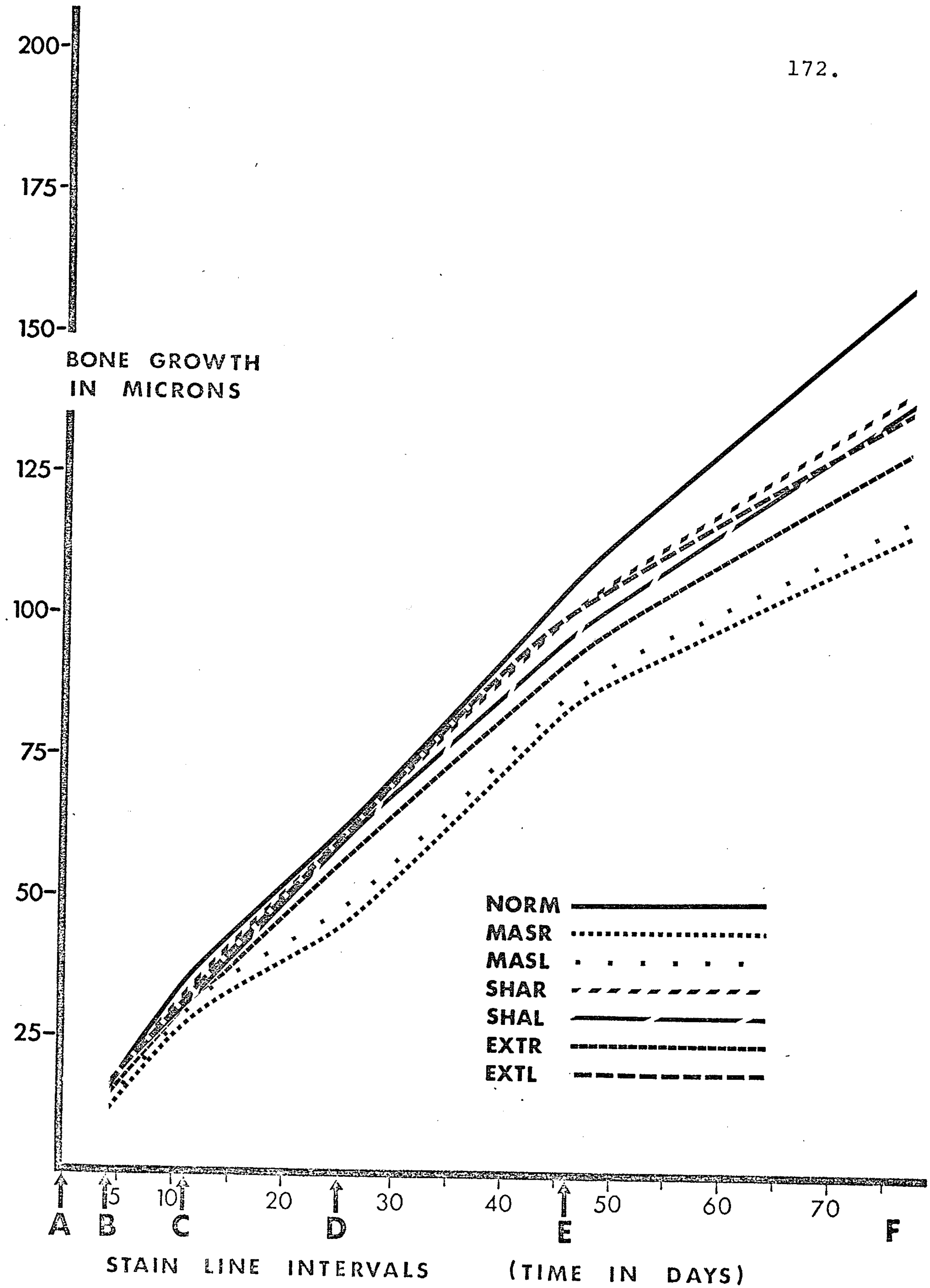


Figure 63. Cumulative Bone Apposition at Cranium Site 46.

TABLE XVII

INCREMENTS OF BONE APPOSITION AT THE TEMPORAL RIDGE

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 25						
NORM	46	8	62	12	140	16	225	13	185	20	658
MASR	16	4	87	11	56	7	273	28	66	20	498
MASL	17	2	93	15	61	10	281	18	73	17	525
SHAR	57	9	58	10	168	30	233	31	156	28	672
SHAL	51	9	59	10	187	40	244	30	163	29	704
EXTR	61	9	49	9	149	11	151	12	93	13	503
EXTL	57	7	50	6	139	14	151	11	97	9	496
					CRANIUM SITE 34						
NORM	85	27	88	21	346	51	369	19	284	36	1172
MASR	61	16	190	18	167	20	493	37	169	31	1080
MASL	62	14	149	32	238	34	486	37	156	31	1091
SHAR	106	13	115	15	291	53	377	53	248	29	1137
SHAL	103	11	135	14	276	52	418	69	261	32	1193
EXTR	137	16	89	13	274	31	298	32	156	17	954
EXTL	127	12	81	9	277	28	304	49	159	14	948
					CRANIUM SITE 45						
NORM	18	2	32	3	69	11	134	12	372	31	625
MASR	9	1	27	3	30	4	185	33	206	46	457
MASL	8	1	21	2	28	5	202	33	190	40	449
SHAR	16	1	19	3	62	16	159	37	365	38	621
SHAL	15	2	22	2	67	17	156	35	392	52	652
EXTR	21	1	23	2	67	6	121	13	293	22	525
EXTL	20	1	22	2	66	5	116	11	315	29	539
					CRANIUM SITE 46						
NORM	14	1	21	1	26	2	45	2	47	4	153
MASR	11	1	16	3	17	2	40	2	28	4	112
MASL	11	1	19	2	16	1	41	3	28	4	115
SHAR	15	1	17	2	28	3	41	3	36	5	137
SHAL	15	2	15	2	29	4	38	3	38	5	135
EXTR	13	1	15	1	27	2	38	2	33	4	126
EXTL	14	1	16	2	31	2	40	3	33	4	134

(Continued)

TABLE XVII (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 54						
NORM	20	2	31	4	33	4	71	10	81	13	236
MASR	17	3	16	2	22	2	54	10	36	15	145
MASL	20	3	15	1	22	3	64	9	48	17	169
SHAR	22	2	18	2	41	6	56	7	57	14	194
SHAL	28	5	19	3	44	6	60	5	51	4	202
EXTR	18	1	18	2	50	5	41	5	37	5	164
EXTL	17	2	18	2	44	5	43	4	28	4	150
					CRANIUM SITE 55						
NORM	19	3	39	7	133	29	178	27	428	40	797
MASR	11	1	20	5	32	6	229	33	190	40	482
MASL	10	0	12	2	32	12	214	33	192	39	460
SHAR	16	2	14	2	81	18	189	46	471	56	771
SHAL	22	3	21	2	85	32	219	41	498	56	845
EXTR	31	4	45	5	116	19	150	15	378	33	720
EXTL	32	6	40	7	105	20	167	16	393	41	737

<u>Experimental Groups</u>. A review of significant differences from normal growth revealed that the sham operation group deviated the least from normal behavior. The sham differences were not significant at the sites on the frontal bone. Slower growth did occur for the sham animals at the parietal bone sites (P = .01) always during the BC interval. Thus, an important temporary effect was noted that did not occur immediately after surgery as was the finding for the masseterectomy group.

Significant differences were noted between experimental groups for numerous growth increments as well as total growth for these sites. The details of these interactions need not be presented, but the general observation that each experimental group responded in individual fashion should be noted. The existence of adaptive adjustments specific in velocity change, amount and timing may be postulated with such supportive evidence in view.

The masseterectomy group curves were of particular interest since the temporal ridge gives attachment to the temporalis muscle and these sites might be expected to reveal some growth compensation after masseter removal. The growth curves presented their usual repeating biphasic design but a dramatic reduction in the total amount of bone apposition occurred (Table XVII). The deficiency developed because there was a greater lag in apposition during the declining phases than was compensated by the faster than normal growth phases. The significance of the variations from normal rates was usually in the order of the 1 per cent level of confidence, although some increments were not statistically different. The magnitude of alterations in bone deposition was proportionately the same for sites in Region VI and Region VII, suggesting a common influence. There were no large side differences.

The development of the temporal ridge was also affected in the extraction animals. The first half of the experimental period yielded normal growth for this group with the exception of a tendency for a rate decline during the BC interval which was significant at Sites 45, 46 and 54. The disparity in the amount of total bone deposition resulted from marked rate declines in the latter half of the experimental period that were significant at all but the ridge sites measured on the parietal bone. Such a developmental scheme was not due to the age difference between normal and experimental animals but many reflect the chronic nature of alterations produced by tooth extraction.

ALVEOLAR PROCESS

It was expected that the extraction group would display the greatest growth alterations at the alveolar process sites numbered 22, 23 and 31. Such was found to be the case. The operated side of the extraction animals revealed reorganization and healing events at Site 22. The amount of new bone deposition was minimal (Figure 64) and occurred only after the C stain injection (Table XVIII). The discrepancy was highly significant at less than the 1 per cent level when comparison was made to normal growth. There was, of course, also a highly significant side difference and it was interesting to note that the unoperated side was also affected; growing significantly less than normal during the BC, CD and DE intervals (P = .01).

The sham animals did not present any significant digressions from normal growth. The masseterectomy group followed its usual course with significant growth reduction in the AB, CD and EF intervals (P = .01). Except for the EF interval, no significant variations were established between sham and masseterectomy increments. These groups also presented no side differences of note.

A reverse of extraction group growth behavior was observed at Site 23 and was interpreted as a typical healing response designed to strengthen a weakened area of bone.

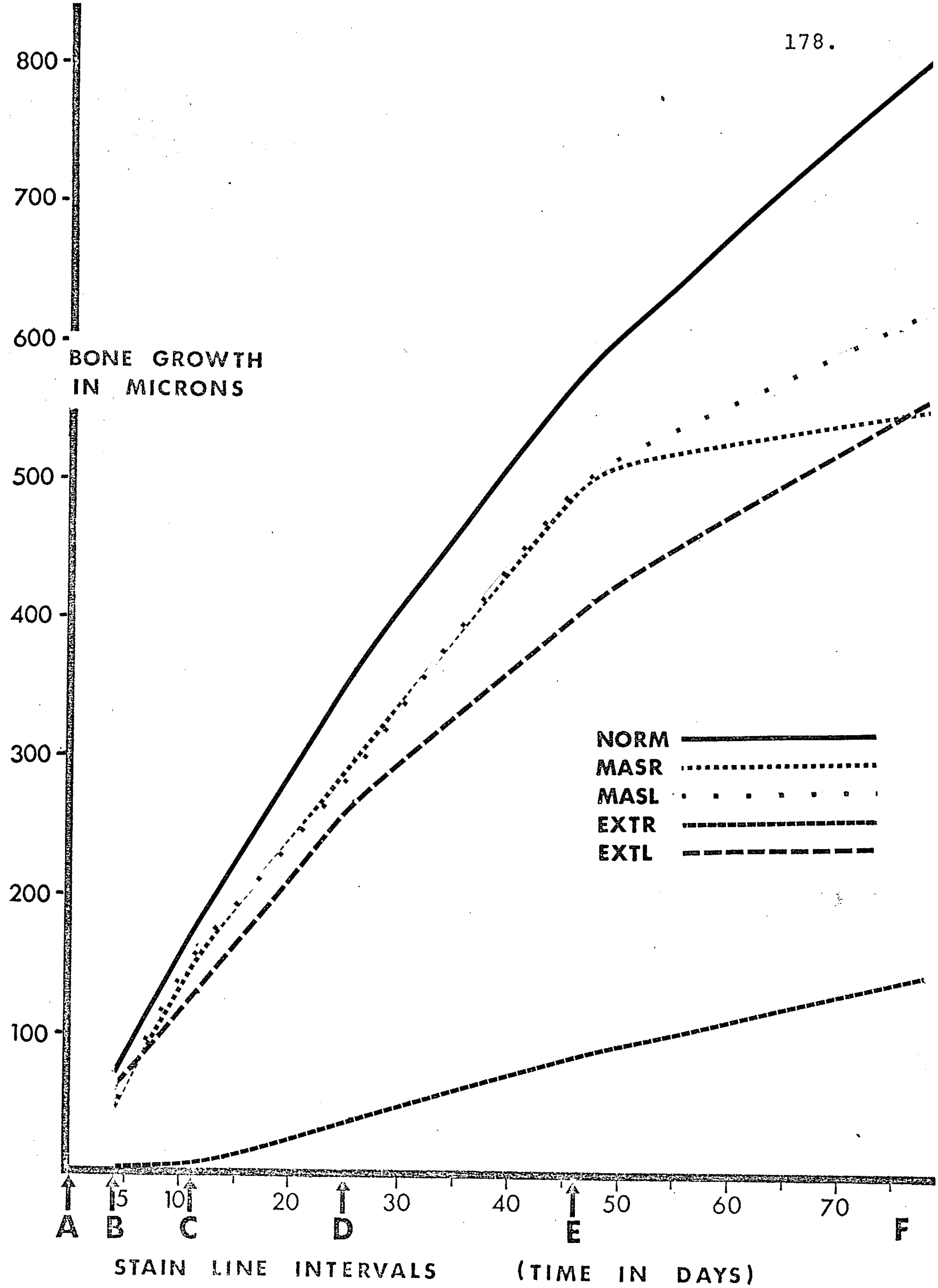


Figure 64. Cumulative Bone Apposition at Cranium Site 22.

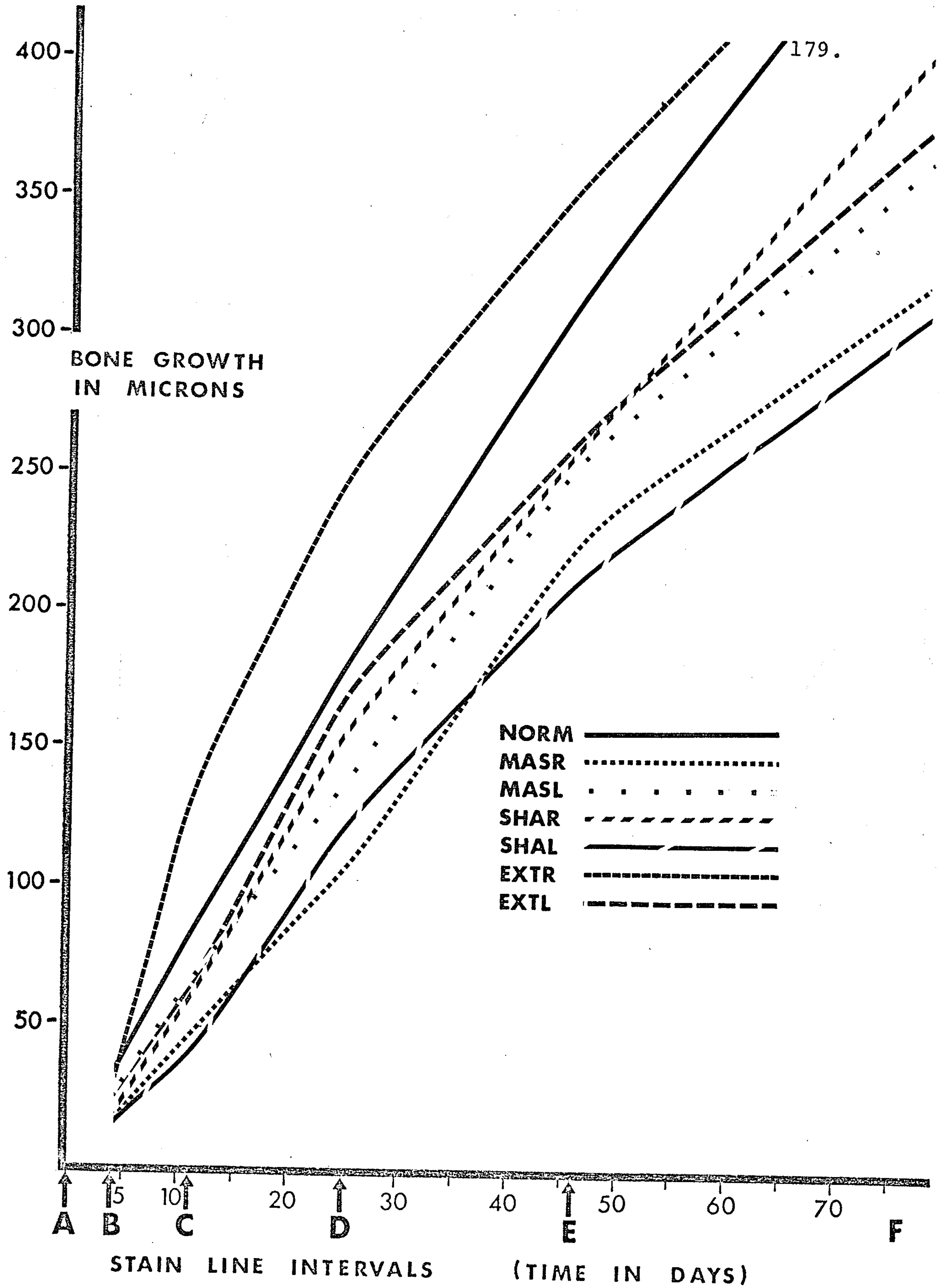


Figure 65. Cumulative Bone Apposition at Cranium Site 23.

TABLE XVIII

INCREMENTS OF BONE APPOSITION AT THE ALVEOLAR PROCESS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 22						
NORM	69	6	107	8	182	9	220	7	202	15	780
MASR	42	5	109	10	142	10	210	13	40	60	543
MASL	42	6	117	15	122	14	227	12	98	17	606
SHAR	58	5	86	8	174	19	192	13	158	16	668
SHAL	53	4	91	10	190	11	206	13	156	14	696
EXTR	1	1	1	1	33	17	47	8	56	12	138
EXTL	68	3	56	14	140	17	146	16	144	17	554
					CRANIUM SITE 23						
NORM	32	3	50	5	98	7	133	13	146	14	459
MASR	17	4	32	8	61	10	122	22	81	16	313
MASL	26	8	42	10	76	16	116	23	96	21	356
SHAR	19	3	43	12	99	19	104	17	127	28	392
SHAL	16	4	26	6	84	18	91	15	84	15	301
EXTR	31	7	112	29	114	18	104	17	119	47	480
EXTL	25	4	41	8	111	13	91	13	100	15	368
					CRANIUM SITE 31						
NORM	33	5	53	14	104	37	111	17	121	13	422
MASR	0	0	0	0	0	0	163	17	91	24	-
MASL	0	0	0	0	0	0	176	18	88	14	-
SHAR	20	0	105	0	275	0	238	10	173	21	811
SHAL	30	0	80	0	245	0	209	32	184	31	748
EXTR	0	0	0	0	11	11	27	19	95	14	-
EXTL	0	0	0	0	10	10	50	26	159	14	-

The operated side disclosed a rapid acceleration of deposition during the BC interval (P = .01) which resulted in slightly more total apposition (Figure 65). The remaining experimental groups demonstrated no significant differences from normal save in the smaller AB increment (P = .05) for the operated side of the masseterectomy and unoperated side of the sham group. Such minor statistical differences occurred at many instances in the course of this study and should not be stressed in the overall interpretation of results.

Observations at Site 31 were limited to the DE and EF intervals because of the resorption of the early stain lines during the process of trabecular reorganization. The extraction group again was adversely affected. The right side grew less than normal during the DE interval (P = .01) but so did the left side (P = .05). The side difference was more pronounced during the EF interval when the operated side rate was much slower than the unoperated side rate (P = .01).

Both masseterectomy and sham groups were subject to growth stimulation during the DE interval (P = .01 for sham group). However, a reaction of rate decline was noted for the masseterectomy group during the last period. These events indicate the customary growth pattern for sham and masseterectomy groups at the retromolar pad.

MUSCLE ATTACHMENTS

A series of sites in the Squama Temporal Region located in the area of attachment of the medial pterygoid and masseter muscles was examined to determine if alterations suggestive of specific instances of stimulation or retardation of bone growth could be found. These sites are illustrated in Figure 20.

At Site 40, the pterygoid muscle attachment, only the general growth curve configurations were revealed for each study group (Figure 66). None of the differences were significant. There were no significant side differences. The endocranial site, number 41, also did not manifest significant total growth disturbances. A deceleration in all but the operated side of the masseterectomy group during the BC interval was significant (P = .01).

The near normal growth rate of the operated side of the extraction group during the CD interval was not mirrored by the operated side (P = .05). A possibility of unilateral alterations in cranial base development existed in the extraction group.

Growth at another endocranial site (42), located opposite the zygomatic process of the temporal bone, supported the supposition of a local effect as a consequence

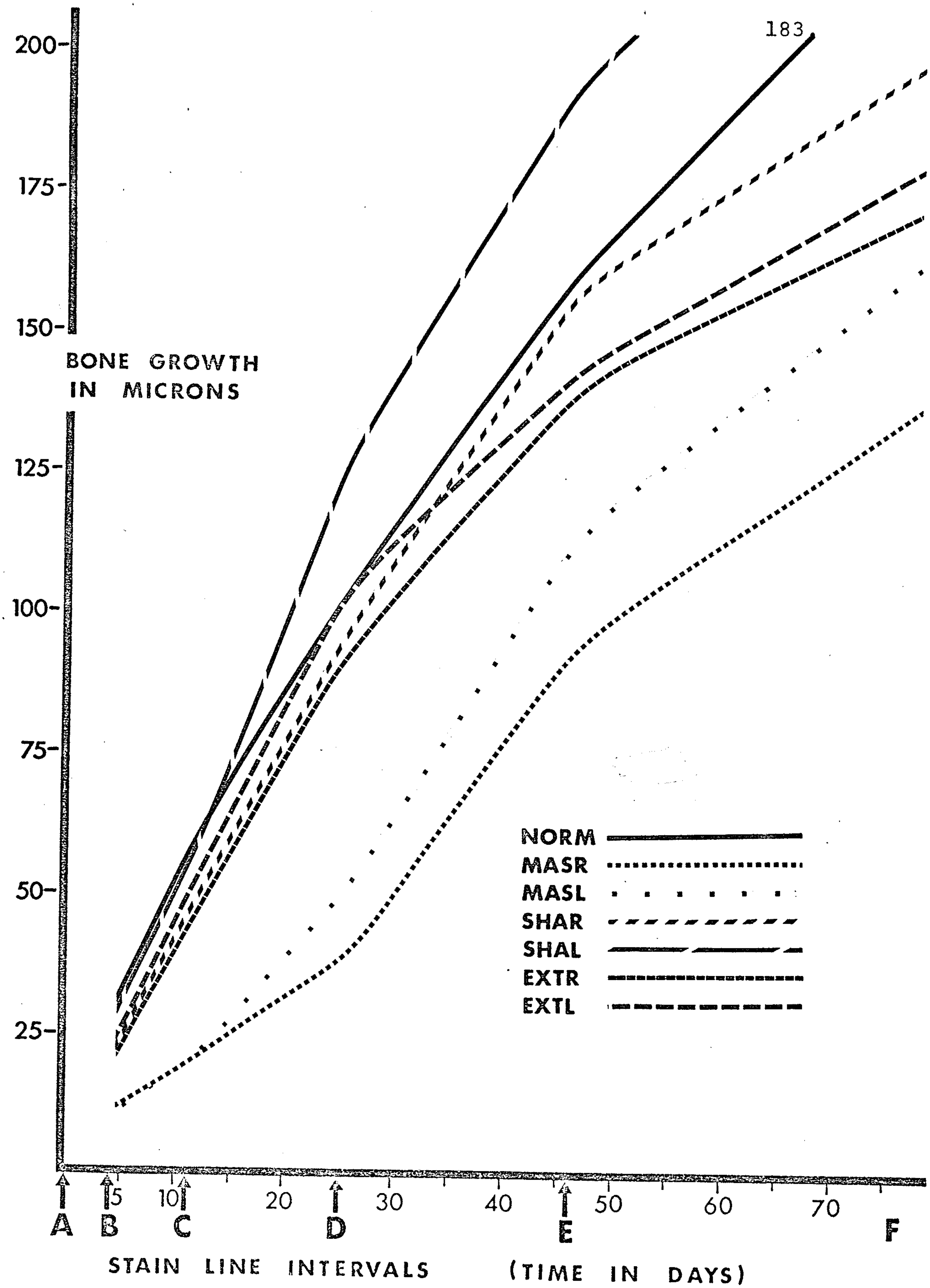


Figure 66. Cumulative Bone Apposition at Cranium Site 40.

TABLE XIX

INCREMENTS OF BONE APPOSITION NEAR MUSCLE ATTACHMENTS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 17											
NORM	245	18	253	18	456	37	614	39	499	53	2067
MASR	178	22	299	21	296	32	693	68	266	58	1732
MASL	155	8	327	27	295	32	650	51	238	52	1665
SHAR	206	16	242	20	483	64	560	46	430	36	1921
SHAL	206	12	279	32	432	59	609	55	418	40	1944
EXTR	219	16	135	19	456	28	438	23	280	12	1528
EXTL	212	14	200	19	401	32	428	20	270	18	1511
CRANIUM SITE 30											
NORM	42	10	91	27	206	9	331	26	245	34	915
MASR	0	0	0	0	180	30	399	35	106	32	-
MASL	0	0	158	18	410	33	108	26	0	0	-
SHAR	0	0	0	0	150	0	366	49	303	50	-
SHAL	0	0	0	0	200	0	445	64	300	39	-
EXTR	75	5	55	5	268	68	225	75	130	30	753
EXTL	0	0	0	0	160	0	290	0	135	15	-
CRANIUM SITE 40											
NORM	29	9	31	5	45	9	59	8	55	8	219
MASR	10	0	10	0	18	3	58	11	38	9	134
MASL	10	0	10	0	30	8	66	16	44	14	160
SHAR	21	4	25	3	51	11	63	12	36	8	196
SHAL	27	5	31	3	71	21	69	11	118	78	316
EXTR	21	6	25	5	47	10	49	9	29	7	171
EXTL	21	6	29	4	55	7	40	7	33	8	178
CRANIUM SITE 41											
NORM	39	6	72	5	74	10	98	13	75	11	358
MASR	15	0	75	10	57	22	123	15	30	8	300
MASL	13	3	32	9	63	9	113	16	42	18	263
SHAR	24	3	33	3	106	17	93	15	58	12	314
SHAL	33	4	41	4	109	13	80	15	74	20	337
EXTR	43	8	26	4	66	9	66	8	60	10	261
EXTL	44	4	34	3	94	12	73	7	61	10	306

(Continued)

TABLE XIX (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 42											
NORM	25	2	25	2	31	2	43	3	34	5	158
MASR	13	1	26	2	19	5	41	6	19	7	118
MASL	11	1	28	5	19	3	34	5	22	7	114
SHAR	17	2	17	2	34	6	36	8	25	9	129
SHAL	21	2	12	2	28	6	41	7	24	4	126
EXTR	12	2	10	2	25	3	21	5	13	5	81
EXTL	16	2	12	2	28	3	24	4	14	4	94
CRANIUM SITE 43											
NORM	100	24	132	11	235	23	281	21	171	17	919
MASR	111	12	152	14	182	17	436	38	98	19	979
MASL	122	23	193	22	247	53	394	48	107	14	1063
SHAR	115	12	128	18	323	42	371	50	262	25	1199
SHAL	114	11	135	21	294	51	346	51	221	17	1110
EXTR	86	9	64	6	167	25	148	25	95	14	560
EXTL	73	9	74	12	230	40	155	15	87	10	619
CRANIUM SITE 44											
NORM	23	2	24	2	34	5	42	5	30	3	153
MASR	10	1	15	3	18	4	118	30	28	6	189
MASL	13	1	35	6	34	6	85	12	33	9	200
SHAR	12	2	7	2	27	8	27	10	31	11	104
SHAL	16	3	12	3	30	9	26	10	30	8	114
EXTR	10	2	5	1	22	4	17	4	5	2	59
EXTL	10	3	7	2	21	6	19	4	8	3	65
CRANIUM SITE 53											
NORM	42	9	69	13	127	13	177	12	147	16	562
MASR	30	10	145	15	70	5	216	18	81	19	542
MASL	30	10	90	15	114	47	206	26	72	8	512
SHAR	24	3	52	11	142	20	161	28	114	10	493
SHAL	32	4	58	11	130	18	173	19	138	22	531
EXTR	43	3	54	7	150	15	131	14	86	6	464
EXTL	44	6	58	8	117	14	130	16	91	8	440

of molar extraction since the extraction group grew least (P = .01). Sham operation and masseterectomy group growth was also retarded, but not as significantly (P = .05). This latter finding was due to the initial growth decline shared by all experimental groups (P = .01), which resulted in less total apposition.

Masseter Muscle. The attachments of the masseter muscle located in the First Molar, Zygomatic, Squama Temporal and Tympanic Bulla Regions displayed similar growth interrelations among groups. Variations of this pattern dealt mainly with the sham group curves. The growth curves for Sites 43 and 44 are displayed in Figures 67 and 68, respectively. The major features of the shared pattern were the stimulation of apposition demonstrated by the masseterectomy group and the decreased growth of the extraction group. Both results were significant at the 1 per cent level. The operated side developed more slowly in both groups but the difference was more significant in the masseterectomy (P = .01) than in the extraction (P = .05) group. It will be remembered that the masseteric ridge areas in the mandible revealed the same reactions.

The sham group curve behaved differently at each site. At Site 43, much more apposition than normal was recorded while Site 44 evidenced less than normal bone

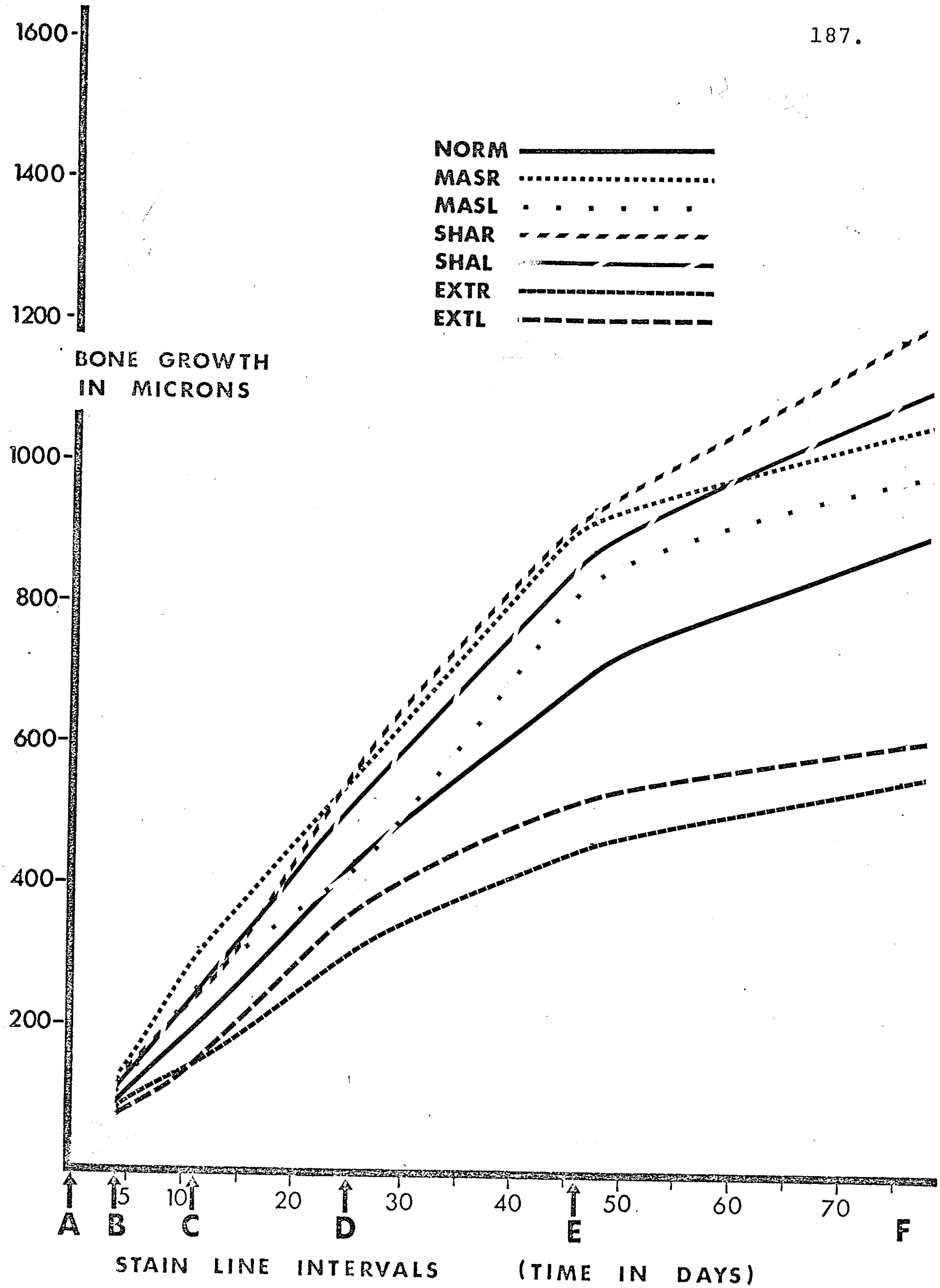


Figure 67. Cumulative Bone Apposition at Cranium Site 43.

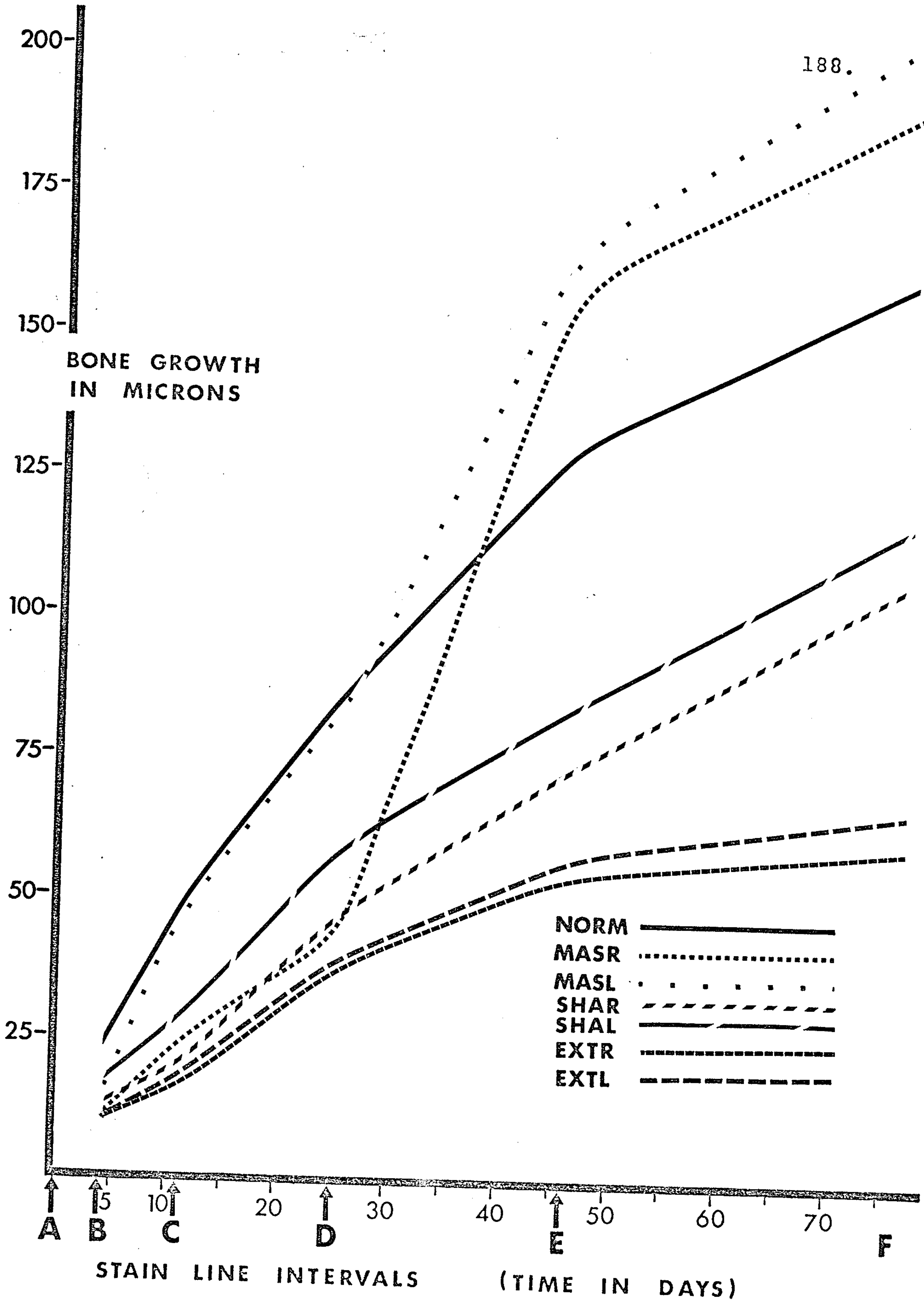


Figure 68. Cumulative Bone Apposition at Cranium Site 44.

deposition. Both variants were significant at the 1 per cent level during a certain time span, but not significant in total growth comparison.

Site 53 measurements yielded a more moderate form of the effects reported for Sites 43 and 44. Growth at Site 53 was also about 2/3 of that observed at Site 43. The rate of resorption on the medial surface of the zygoma itself was so rapid that only the DE and EF interval readings were obtained. Comparison of these increments revealed a single significant finding of reduced growth of <u>both sides</u> of the masseterectomy group significant at the 1 per cent level. The side difference was remarkably small (only 4%). This data may seem inconsistent with gross observations.

The anterior attachment of the masseter muscle on the zygomatic process of the maxilla was represented by Site 17. It was interesting to note that bone apposition at this region, as was the case at Sites 30, 43 and 53, was not in the direction of muscle pull. No evidence of a "specific effect" reaction similar to that observed at Sites 43 and 44 was discerned at Site 17. The commonly found general growth curve pattern showing no side differences is illustrated in Figure 69 for this site. It might be stated that this site was the fastest growing of the 88 sites studied.

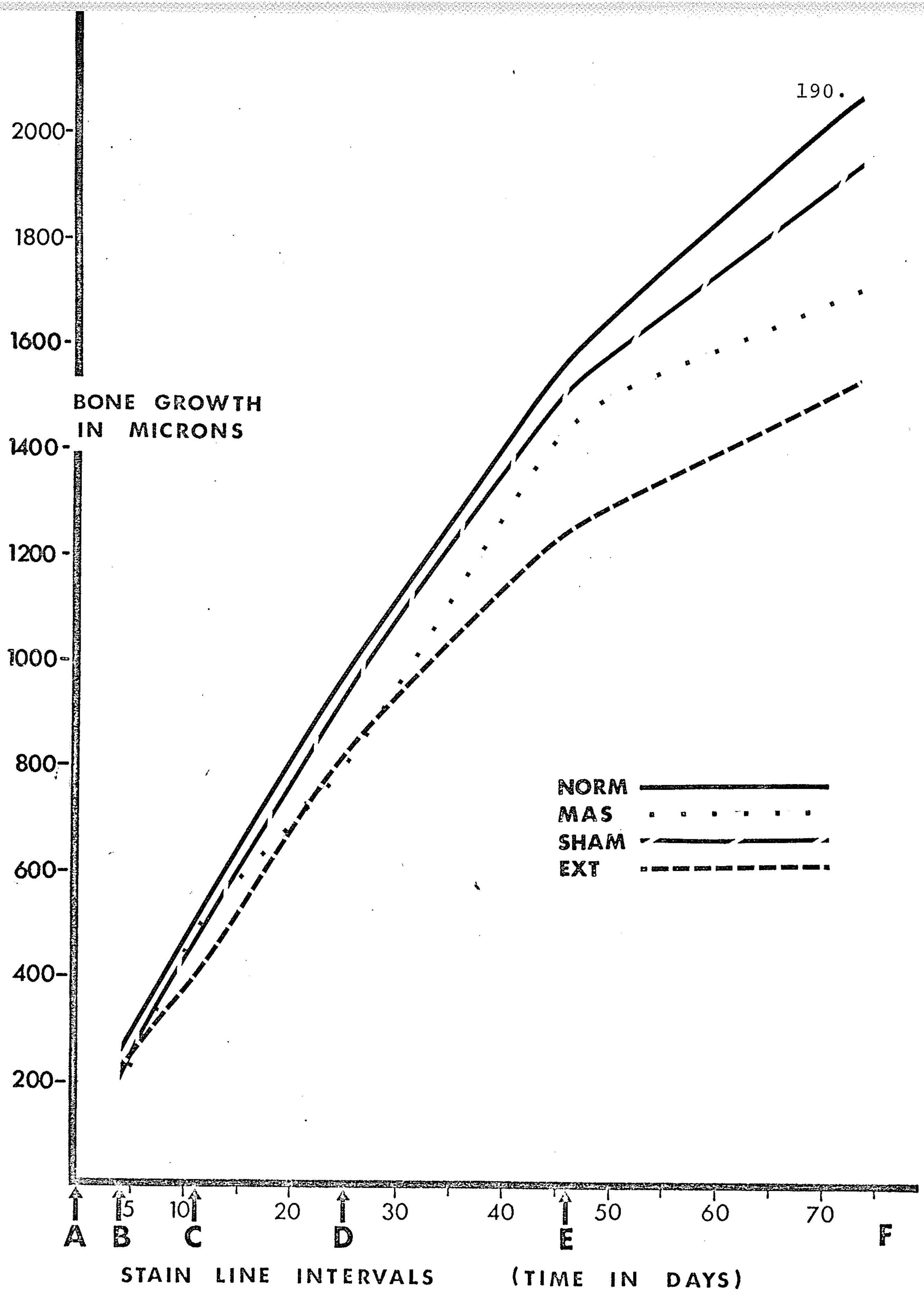


Figure 69. Cumulative Bone Apposition at Cranium Site 17.

INCISOR SOCKET

The growth of the premaxilla in the area above the incisor socket was assessed by comparing measurements made at Sites 3 and 9 in the Incisor and Premaxillary Regions, respectively. Large amounts of bone deposition were recorded at both sites but Site 9 grew more. The growth direction also changed, as Site 3 grew buccally while Site 9 grew more superiorly. The inner (intranasal) surfaces were subject to resorption as the width of the nasal cavity increased. A consideration of the amounts of lateral growth of the premaxilla is of importance to an appreciation of the adjustments made at the nasopremaxillary suture.

At Site 3, the growth curves manifested the typical configurations for each study group (Figure 70). The most significant deviations registered were less apposition for the extraction group during BC, DE and EF intervals ($P = .01$). Reduced growth of the extraction group was also disclosed at Site 9 where the significance occurred during the AB, BC and EF intervals ($P = .01$). At this location, however, the reduction was also manifested in the masseterectomy group (Figure 71) due to the large initial depression ($P = .01$). The sham group recovered from the initial lag and achieved total growth approximating normal values. The sole significant side difference was the greater rate of the operated

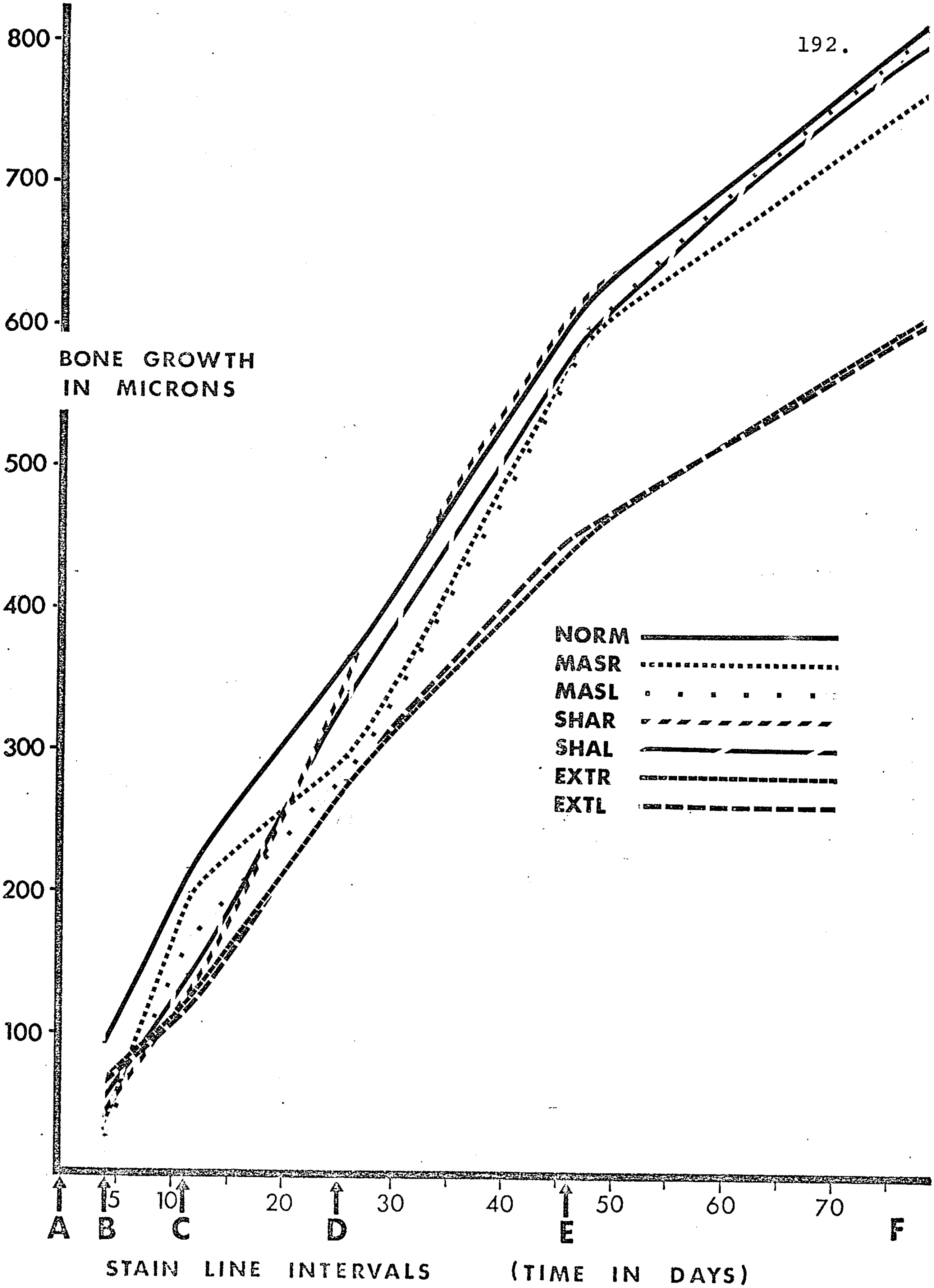


Figure 70. Cumulative Bone Apposition at Cranium Site 3.

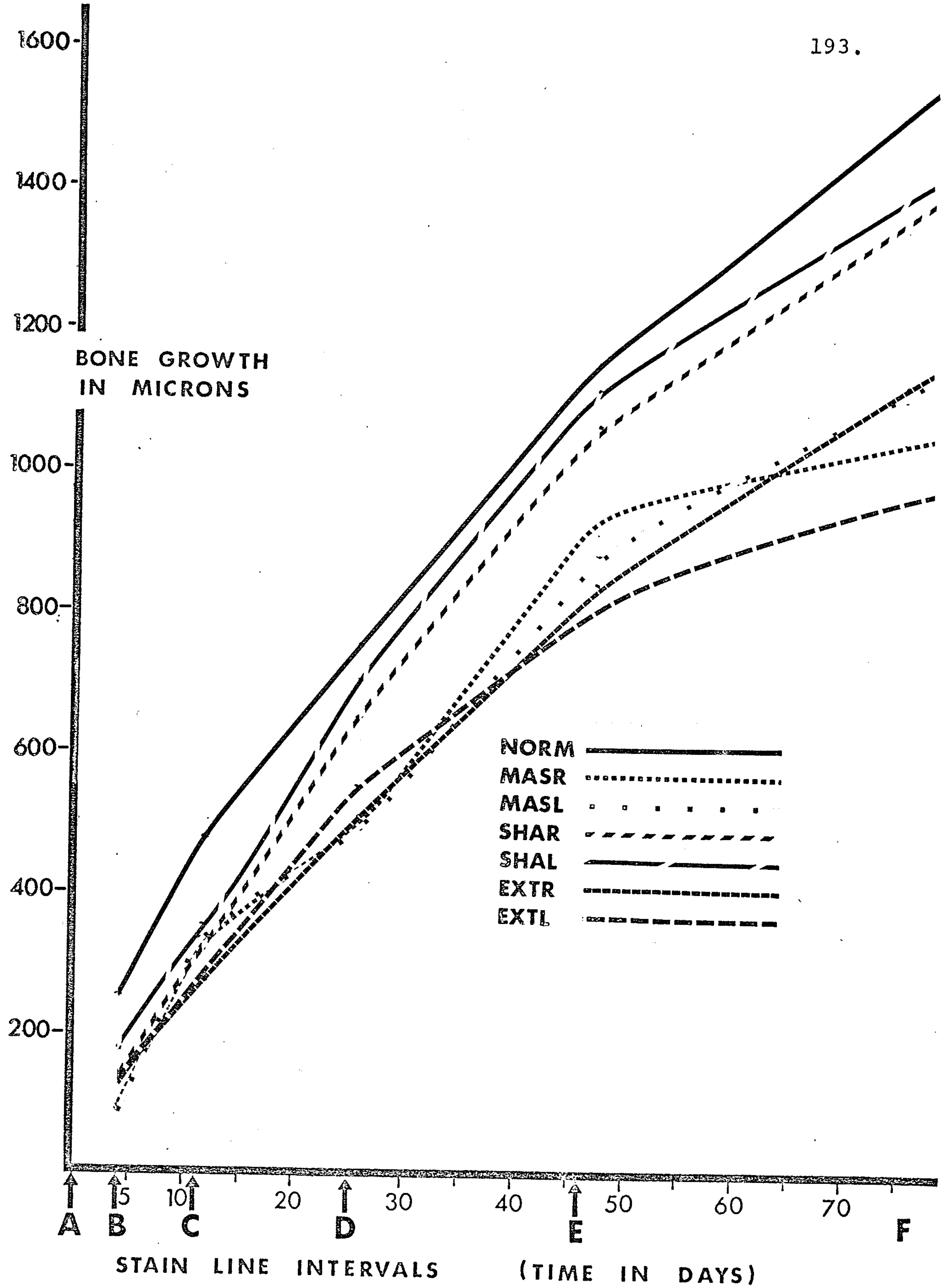


Figure 71. Cumulative Bone Apposition at Cranium Site 9.

TABLE XX

INCREMENTS OF BONE APPOSITION NEAR THE INCISORS

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 2						
NORM	20	2	27	2	33	3	70	5	87	9	237
MASR	11	2	21	3	17	3	57	8	37	13	143
MASL	9	1	21	2	18	2	60	11	40	14	148
SHAR	13	1	13	3	25	6	51	8	45	7	147
SHAL	15	2	14	3	25	3	43	8	37	6	134
EXTR	12	2	13	3	24	3	48	7	45	9	142
EXTL	11	2	13	3	26	6	49	5	45	7	144
					CRANIUM SITE 3						
NORM	84	11	121	14	151	15	269	24	200	9	825
MASR	25	0	173	23	95	5	306	26	159	19	758
MASL	20	0	148	32	110	10	326	26	199	31	803
SHAR	50	0	73	7	229	37	274	42	174	25	800
SHAL	61	1	74	15	208	27	272	20	178	18	793
EXTR	65	9	59	7	160	19	169	8	149	15	602
EXTL	64	9	53	8	167	21	178	18	130	8	592
					CRANIUM SITE 9						
NORM	240	26	234	14	268	21	406	23	334	39	1482
MASR	84	7	238	21	169	16	450	32	109	33	1050
MASL	81	6	249	20	166	10	352	95	257	118	1105
SHAR	158	12	164	13	328	43	429	28	293	24	1372
SHAL	166	16	189	21	352	47	417	35	278	7	1402
EXTR	161	10	111	14	253	14	318	22	186	21	1029
EXTL	163	9	115	9	252	17	275	18	167	16	972

side of the extraction group during the DE interval ($P << .01$). A large similar side difference was recorded for the extraction group during this interval but could not be shown to be statistically significant. These side differences suggested the existence of recovery mechanisms to re-establish symmetry. The attachment of the anterior deep head of the masseter muscle was located near Site 9 and the unilateral response in the masseterectomy group, which was twice as large as that in the extraction group, could have been a reflection of the growth spurt commonly noted in areas of extirpated muscle attachment.

There were no differences among the experimental groups in bone apposition at Site 2. Apposition at this location was a measure of the buccal drift of the incisor socket within the premaxilla in the incisor region. The growth curves of the experimental groups were all superimposed. All experimental groups grew slower than normal as indicated in Table XX. In view of the similarity of experimental group responses, it is likely that the large amount of apposition registered for the normal group does not represent a real difference but the selection of a more inferiorly located measurement site. All experimental groups were measured by the same observer.

CRANIAL BASE

The growth in the superior direction of the cranial base was recorded at Sites 32, 38 and 39 which were in the midline, thus no separate measurements were shown for sides in Table XXI. Resorption on the inferior surface was involved in the relocation pattern therefore the mean measurements recorded for the early increments were based on only a few animals for the faster growing groups. The AB measurement for the normal group may be incorrect for Site 32. Site 33 was located to provide assessment of the lateral apposition of the presphenoid bone in the Zygomatic Region.

The experimental observations demonstrated that growth reduction was greatest for the masseterectomy group in the Zygomatic Region where AB and EF declines were significant (P = .01). The total growth of sham and extraction animals was not significantly less than normal.

In the Squamotemporal Region, it was the extraction group that revealed the least amount of deposition on the basisphenoid superior facing surfaces, although this difference was not significant. The growth rate of Site 39 was faster than that of Site 38 to allow the thickness of the basisphenoid to increase as cortical drift progressed superiorly. Surfaces facing inferiorly showed bone resorption as indicated in Figure 20. The growth curves followed the typical configuration as illustrated in Figure 72 which depicts growth at a representative site.

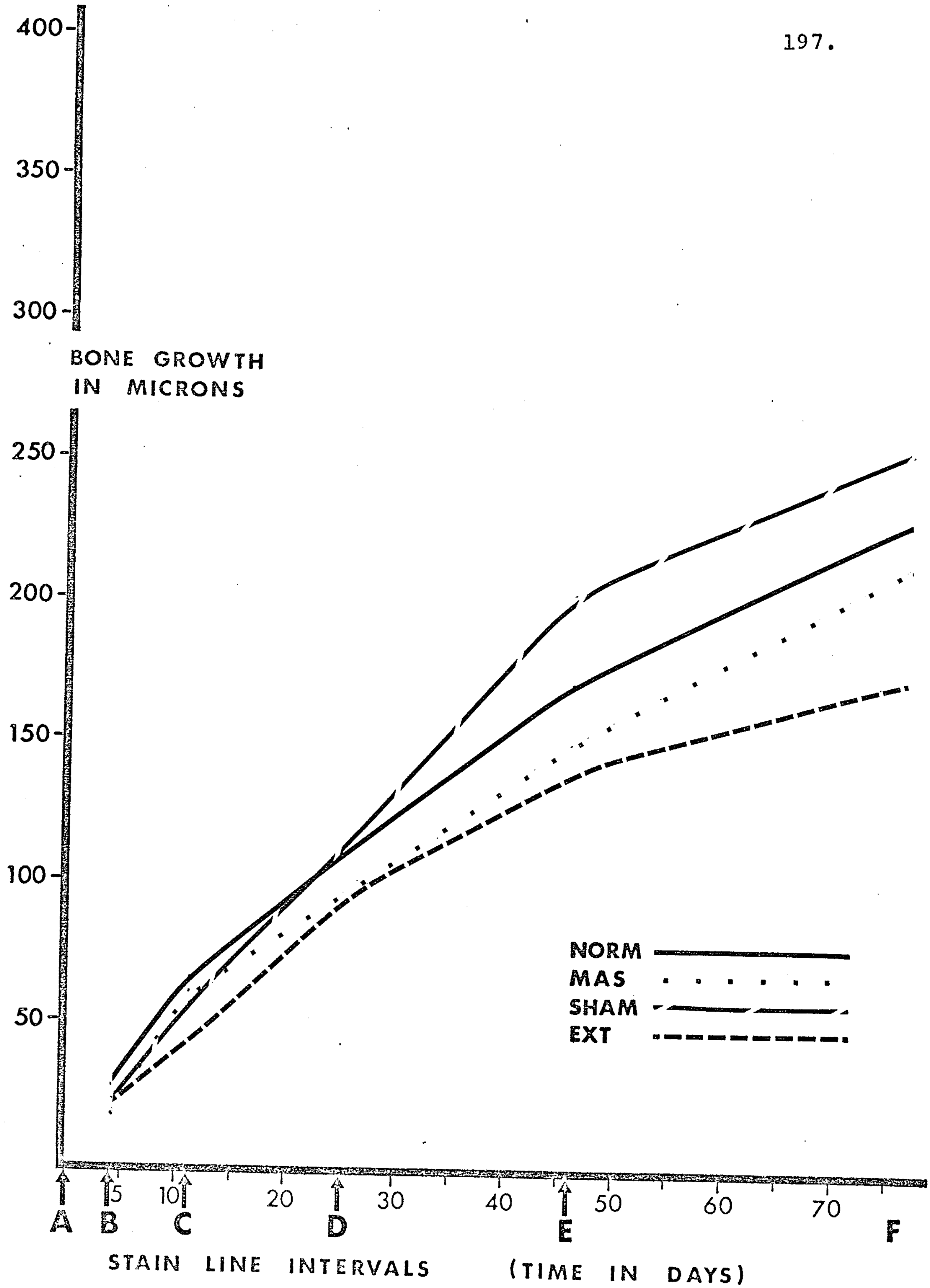


Figure 72. Cumulative Bone Apposition at Cranium Site 38.

TABLE XXI

INCREMENTS OF BONE APPOSITION AT THE CRANIAL BASE

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 32											
NORM	100*	50	50	0	58	18	112	14	99	12	419*
MAS	13	2	23	6	24	4	96	25	29	8	185
SHA	38	11	35	8	105	36	98	30	87	15	363
EXT	40	12	34	6	69	11	94	18	67	10	304
CRANIUM SITE 33											
NORM	25	0	25	0	45	0	38	6	57	7	190
MASR	9	1	17	7	13	6	36	8	18	4	93
MASL	8	1	15	5	10	3	37	11	21	6	91
SHAR	13	2	12	2	42	4	65	10	28	6	160
SHAL	15	0	18	2	43	6	76	7	33	7	185
EXTR	15	3	16	1	41	7	39	7	41	15	152
EXTL	15	10	15	5	68	22	61	15	43	10	202
CRANIUM SITE 38											
NORM	28	3	39	4	48	5	61	11	57	9	233
MAS	18	2	45	13	36	5	56	6	66	21	221
SHA	24	2	37	5	58	3	93	12	49	9	261
EXT	21	3	25	4	51	7	47	7	34	7	178
CRANIUM SITE 39											
NORM	15	0	75	5	100	15	99	8	86	8	375
MAS	15	5	75	25	53	13	197	22	54	13	394
SHA	50	0	70	0	225	5	144	26	107	28	596
EXT	37	4	51	10	116	22	65	10	47	8	316

* Questionable AB measurement resulted in an inflated total.

SUTURES

The role of the craniofacial sutures as sites of growth, and adjustment of the relationships of bones has been the subject of numerous investigations. From observation of the gross specimens, it could be deduced that the deviations in the position and relative sizes of bones resulting from masseterectomy and extraction must involve some adjustment of sutural growth patterns.

Midsagittal suture apposition was measured in each of the seven coronal sections of the cranium; both on the dorsal and ventral surface. In a few instances, the nature of the stain lines did not allow the accumulation of sufficient data and the site was not included in the final analysis. Other sutures of note were the internasal and naso-premaxillary sutures.

Internasal Suture. The medial growth of the nasal bones at Sites 6 and 13 proceeded in similar fashion and reflected the modal growth curve configuration for the various study groups. Growth was greater in every case at the anterior site and the unoperated sides showed more activity than the operated. The significant differences between groups were almost identical for both sites and Figure 73 demonstrates the curve pattern for Site 6. The sham curve has been omitted since the only significant

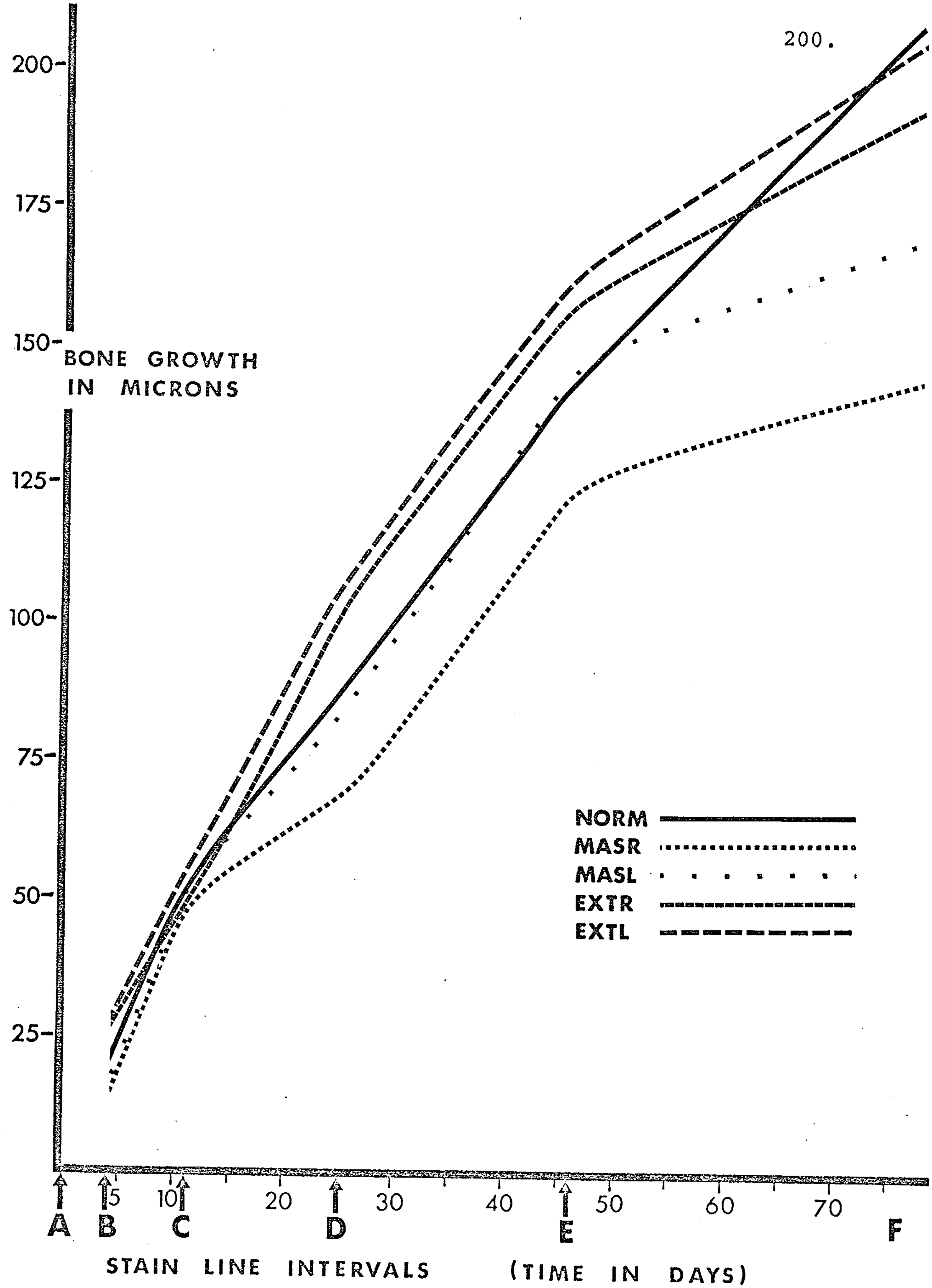


Figure 73. Cumulative Bone Apposition at Cranium Site 6.

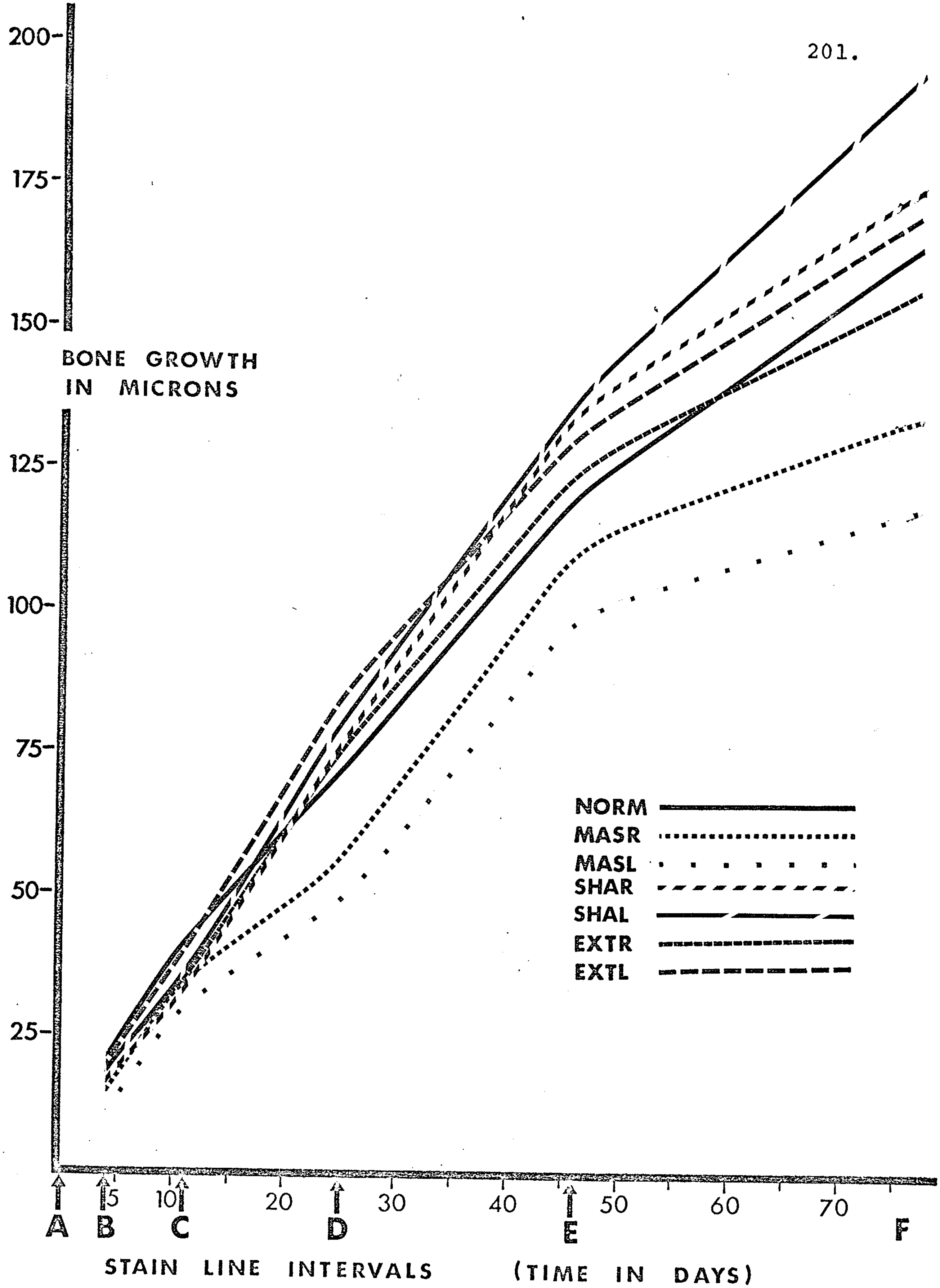


Figure 74. Cumulative Bone Apposition at Cranium Site 7.

TABLE XXII

INCREMENTS OF BONE APPOSITION AT SUTURES

MEAN AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 1						
NORM	23	2	20	1	25	2	41	3	33	2	142
MASR	13	1	15	2	14	1	46	7	12	4	100
MASL	13	1	20	3	14	2	37	4	17	5	101
SHAR	19	1	16	2	31	5	35	4	34	5	135
SHAL	18	2	15	2	29	7	34	4	26	4	122
EXTR	14	1	12	2	31	3	24	3	12	2	93
EXTL	16	3	14	2	32	3	28	5	18	4	108
					CRANIUM SITE 6						
NORM	20	2	32	2	37	3	60	5	58	5	207
MASR	12	1	36	5	20	5	57	6	17	3	142
MASL	12	2	39	4	32	4	65	9	18	3	166
SHAR	20	3	33	4	50	6	62	10	37	4	202
SHAL	16	2	24	2	44	8	68	9	42	5	194
EXTR	25	2	23	2	55	5	56	5	30	3	189
EXTL	27	2	27	3	54	4	56	5	37	4	201
					CRANIUM SITE 7						
NORM	21	1	21	1	31	3	50	3	39	5	162
MASR	13	2	21	2	21	2	58	4	21	4	134
MASL	10	1	20	3	19	2	52	4	17	4	118
SHAR	16	1	15	2	45	7	62	10	35	8	173
SHAL	17	2	17	2	47	8	59	10	52	8	192
EXTR	17	3	16	2	43	6	51	6	29	4	156
EXTL	19	2	20	2	47	8	48	6	35	3	169
					CRANIUM SITE 10						
NORM	26	3	36	3	49	5	85	6	76	9	272
MASR	10	1	31	3	36	3	73	8	38	8	188
MASL	18	4	33	4	32	3	66	7	33	5	182
SHAR	20	1	30	2	71	10	91	11	79	11	291
SHAL	21	3	31	4	64	9	91	12	73	13	280
EXTR	23	2	27	2	66	3	88	5	69	4	273
EXTL	23	2	29	3	70	6	88	6	64	4	274

(Continued)

TABLE XXII (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 13											
NORM	14	2	18	1	22	2	42	3	40	5	136
MASR	6	1	13	2	12	1	31	3	18	3	80
MASL	7	1	15	2	14	2	36	4	20	4	92
SHAR	13	2	12	3	23	4	38	5	27	6	113
SHAL	12	1	14	2	24	4	41	6	33	6	124
EXTR	13	2	15	1	37	2	36	2	25	4	126
EXTL	14	1	18	1	32	2	41	3	30	4	135
CRANIUM SITE 20											
NORM	18	2	51	11	50	10	75	6	91	9	
MASR	15	0	25	10	22	7	66	13	31	9	
MASL	15	0	35	0	50	0	87	23	35	7	
SHAR	0	0	15	0	20	0	97	27	62	12	
SHAL	0	0	0	0	30	0	83	17	65	8	
EXTR	15	0	15	0	82	50	78	14	74	11	
EXTL	30	0	20	0	67	27	79	20	71	8	
CRANIUM SITE 27											
NORM	18	2	21	4	39	10	79	13	68	26	225
MASR	18	5	25	9	21	7	26	13	9	6	99
MASL	16	4	14	4	24	7	30	10	22	7	106
SHAR	16	3	23	11	51	12	59	16	33	12	182
SHAL	19	3	27	6	47	10	44	8	28	6	165
EXTR	26	6	21	6	45	9	37	7	23	4	152
EXTL	32	5	33	9	63	14	61	12	39	8	228
CRANIUM SITE 37											
NORM	29	7	22	2	28	5	38	0	23	0	140
MASR	5	3	4	2	3	2	14	7	2	1	28
MASL	4	1	9	7	4	2	16	5	11	6	44
SHAR	0	0	0	0	4	4	9	7	3	3	-
SHAL	3	2	4	2	5	3	8	4	12	7	32
EXTR	1	1	1	1	1	1	3	2	3	1	9
EXTL	1	1	2	1	4	2	4	2	3	3	14

(Continued)

TABLE XXII (CONTINUED)

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 49						
NORM	20	7	20	2	38	6	65	4	76	9	219
MASR	1	1	3	2	4	2	36	16	27	13	71
MASL	3	2	2	1	2	1	75	24	23	11	105
SHAR	3	1	4	2	46	26	33	12	37	12	123
SHAL	3	2	4	3	46	24	86	36	51	17	190
EXTR	7	3	7	3	49	15	59	14	18	4	140
EXTL	7	3	6	3	32	8	33	7	22	6	100
					CRANIUM SITE 58						
NORM	23	3	28	9	50	1	68	6	94	13	263
MASR	15	5	25	15	30	0	71	14	40	10	181
MASL	17	2	43	11	32	2	65	19	33	14	190
SHAR	3	2	6	4	53	31	73	23	46	15	181
SHAL	7	3	6	3	33	14	119	47	73	15	238
EXTR	0	0	0	0	18	11	46	14	51	9	115
EXTL	5	3	6	4	47	18	56	12	55	11	169

alteration was that the sham group shared in the experimental group rate decline during the EF interval (P = .01).

The important alterations occurred in the masseterectomy group. Overall growth was significantly slower than that of all other groups. When compared to the sham and normal groups, a significance of P = .01 was observed while comparison with extraction growth gave a P value of .05. Every "decline period" in the masseterectomy growth rate for the operated side was significantly less than normal (P = .01). The side difference (P = .05) was developed mainly during the CD interval. Side differences were an infrequent observation and this particular growth disparity between left and right nasal bones should be emphasized. The masseterectomy group was the only group which demonstrated a permanent degree of rostral deviation on clinical examination.

The total amount of extraction group growth was not significantly less than normal. The customary periods of acceleration and deceleration were observed and were significant.

<u>Palatal Suture</u>. The growth alterations recorded for the sham and extraction groups at the midpalatal suture (Site 7, Figure 74) were not noteworthy. Total apposition for all groups was somewhat less than at Site 6. The curve patterns were similar to those of the internasal suture with one critical exception.

The operated side of the masseterectomy group grew more than the unoperated side (P = .05). the reverse of the finding at Sites 6 and 13. An attempt to restore symmetry in the coronal plane was revealed by this growth scheme.

Interincisal Suture. Further support for such an explanation was not forthcoming from the examination of apposition at Site 1. The irregular contour of bone edges at this local and unconcious observer bias may have prevented the finding of a supportive side difference in the masseterectomy group. Both extraction and masseterectomy groups were subject to significantly less deposition at the interincisal site. The usual altered growth patterns prevailed.

Nasopremaxillary Suture. Sites 10 and 20 provided a measure of the lateral bone increments on the nasal bones at the junction with the premaxilla. Table XXII can be examined to reveal the amount of apposition on the lateral margins of the nasal bones was much greater than that on the medial margins.

The growth of sham and extraction animals at Site 10 manifested close adherence to the normal curve. There were no large side differences at this site. The notable finding was the retarded growth of the masseterectomy group which was significantly less ($P = .01$) when compared to that of any other groups. The commonly observed three periods of decline in the masseterectomy pattern were all significantly different from normal.

A variation of this relationship was observed at Site 20 in that the left side of the masseterectomy group approximated normal growth during the CD interval. The difference was not significant, however. The initial stain lines were subject to endosteal resorption so comparisons were limited to the CD, DE and EF intervals.

Metopic Suture. The midsagittal approximation of the frontal bones in the First Molar Region displayed a very significant side difference in extraction group growth. The unoperated side of the extraction group grew much more than normal during the DE interval ($P \ll .01$). This interval marked the beginning of the growth decline of the operated side which was significantly less than normal during the EF interval.

The masseterectomy demonstrated greatly retarded growth but no side differences.

Parietal Suture. The midsagittal union of the parietal bones was represented by Sites 37, 49 and 58 in the Zygomatic, Squama Temporal and Tympanic Bulla Regions, respectively. Examination of the growth increments for these sites in Table XXII revealed that the amount of apposition increases from anterior to posterior sites. Endosteal resorption was responsible for the loss of initial stain lines in many animals so the value of detailed comparisons is limited. There was, however, a generalized tendency for significantly greater growth of the operated side in the extraction and masseterectomy series. The occurrence of fusion in the more posterior regions of the suture was an infrequent finding.

NASAL SEPTUM

The endochondral ossification of the superior lateral (Site 28) and midline (Site 29) aspects of the nasal septum yielded stain lines that were difficult to assess because of the small amounts of growth occurring and the complicated pattern observed in adjacent locations. A few intervals were represented by readings in only one animal as indicated by standard error values of zero in Table XXIII.

At Site 28, the extraction and sham group values were readily assessed and revealed a growth stimulation. The rate increase was significant during the DE interval. The masseterectomy group did not demonstrate increased total growth at this location.

The midline site was characterized by minimal amounts of apposition for all the experimental groups (P = .01) but the extraction group was least affected. The normal values for this site are questionable since they are of a cross-sectional nature only. No AE or AF interval readings were recorded for the normal animals.

The report of continuous side differences in nasal septum bone deposition (Cleall, 1971) was not substantiated by similar findings in the experimental groups. Experimental side differences were not significant and occurred in random fashion.throughout an individual's growth period. The deflection of the nasal septum is probably mediated by cartilaginous adjustments rather than differential bone deposition.

TABLE XXIII

INCREMENTS OF BONE APPOSITION AT THE NASAL SEPTUM

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
CRANIUM SITE 28											
NORM	26	5	23	3	37	4	45	3	34	6	165
MASR	10	0	35	0	20	0	41	5	25	6	131
MASL	30	0	20	0	25	8	51	8	22	8	148
SHAR	26	6	27	10	60	24	69	14	49	11	231
SHAL	29	6	31	8	57	19	30	5	53	15	200
EXTR	30	5	20	4	43	6	64	8	52	9	209
EXTL	26	5	24	2	43	9	71	6	45	4	209
CRANIUM SITE 29											
NORM	16	9	15	5	24	9	18	3	18	2	91
MASR	1	1	3	2	3	2	12	7	3	2	22
MASL	1	1	3	3	1	1	11	5	3	2	19
SHAR	2	1	2	1	6	3	4	3	1	1	15
SHAL	2	1	2	1	6	3	4	3	0	0	14
EXTR	15	0	25	0	0	0	0	0	10	10	50
EXTL	8	3	8	3	3	3	5	5	8	8	32

TYMPANIC BULLA

The occurrence of growth alterations during development of the tympanic bulla demonstrated the far reaching effects of surgical intervention. Every growth site studied was subject to modification of the normal events. Sites 50, 51 and 52 were located at the medial, inferior and lateral positions on the bulla as illustrated in Figure 21. The amount of total growth was found to decrease from site to site in the same order.

The masseterectomy group curves did not follow their usual pattern at Sites 50 and 51 (Figure 75). This was seen as a rare occurrence and suggests that the tympanic bulla were not subject to the same control as the vast majority of growth sites studied, both in the mandible and cranium. In this region, masseterectomy curves followed the normal growth pattern, as did those of the sham group. Greater than normal total apposition was recorded for the masseterectomy group at Site 50 due to the magnitude of the spurt during the BC interval ($P = .01$). Side differences were of no account in this region.

The extraction group followed its customary growth curve and was slower in development at these sites than the other groups. The differences were not statistically significant since extraction group values were derived from the measurement of only one animal.

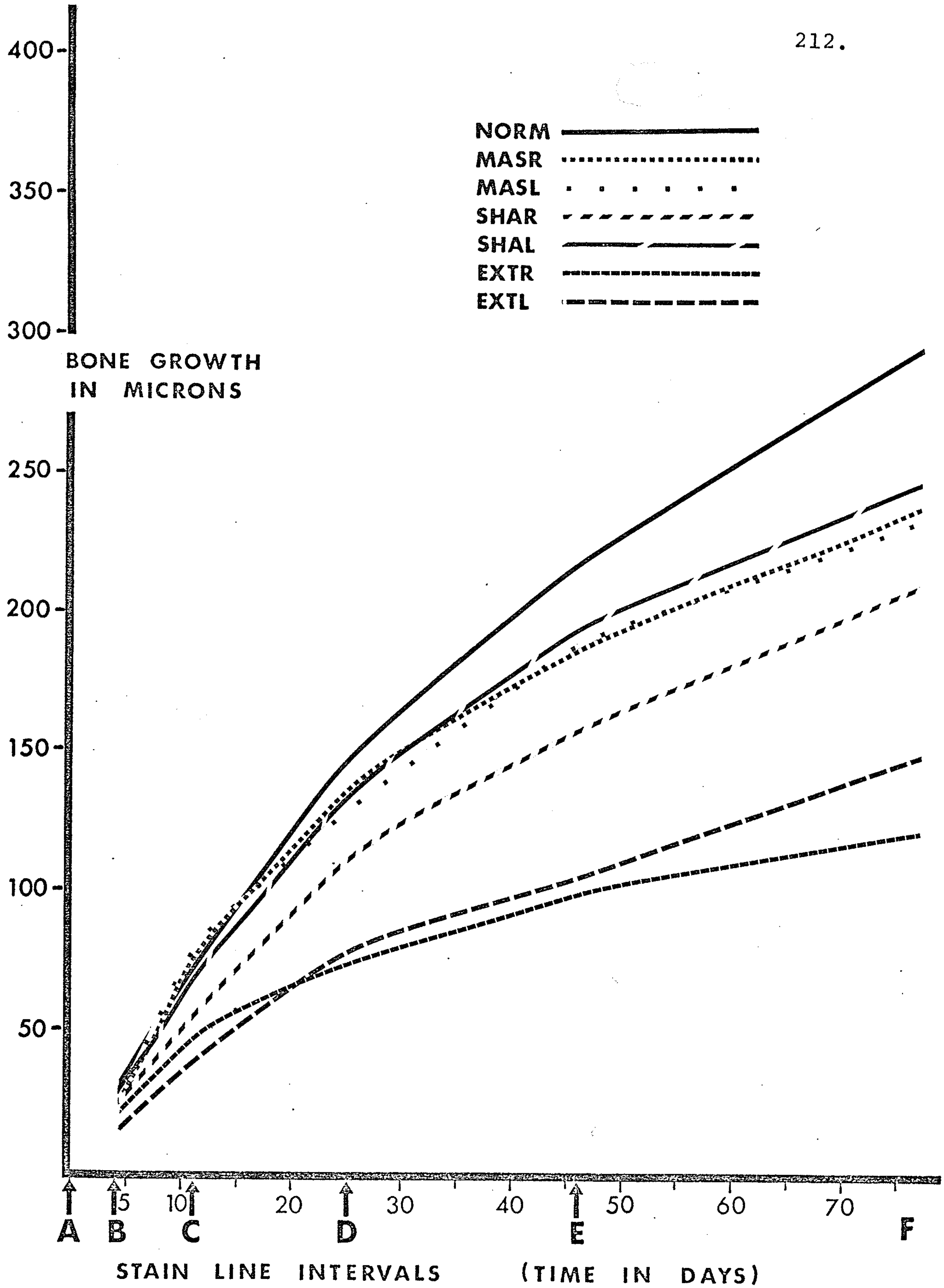


Figure 75. Cumulative Bone Apposition at Cranium Site 51.

TABLE XXIV

INCREMENTS OF BONE APPOSITION AT TYMPANIC BULLA

MEANS AND STANDARD ERRORS IN MICRONS

GROUP	AB MEAN	AB SE	BC MEAN	BC SE	CD MEAN	CD SE	DE MEAN	DE SE	EF MEAN	EF SE	TOTAL
					CRANIUM SITE 50						
NORM	25	4	45	8	86	15	90	8	81	9	327
MASR	28	5	109	24	60	11	104	14	66	9	367
MASL	36	7	99	15	69	12	87	10	48	7	339
SHAR	26	5	40	7	73	16	62	6	53	11	254
SHAL	27	5	39	6	85	12	66	5	57	9	274
EXTR	20	0	15	0	75	0	75	0	65	0	250
EXTL	20	0	30	0	65	0	60	0	85	0	260
					CRANIUM SITE 51						
NORM	31	3	45	4	78	8	72	6	69	7	295
MASR	23	3	55	6	60	11	50	5	45	11	233
MASL	25	2	56	7	49	6	60	6	39	12	229
SHAR	25	2	31	6	57	11	45	9	46	11	204
SHAL	28	3	41	5	68	12	58	7	46	9	241
EXTR	20	0	30	0	25	0	25	0	20	0	120
EXTL	15	0	25	0	40	0	25	0	40	0	145
					CRANIUM SITE 52						
NORM	37	3	44	4	68	10	63	10	45	6	257
MASR	18	2	61	12	36	4	74	10	22	7	211
MASL	22	3	65	13	44	7	54	7	15	5	200
SHAR	31	4	37	8	53	11	41	5	34	5	196
SHAL	36	5	46	8	66	12	53	6	30	7	231
EXTR	25	0	25	0	35	0	45	0	15	0	145
EXTL	25	0	20	0	40	0	30	0	15	0	130

DISCUSSION

General Observations. The technique of microscopic assessment of bone growth at specific sites in the cranio-facial structures of the rat was found to be most efficacious. The vital staining sequence (Sequence 2, Table II) was found to provide clearly visible stain lines (Figures 1 and 2) with a fluorescence microscopy technique. There was no need to use tungsten light. Both the direction and amount of bone apposition as well as the existence of resorptive activity could be determined at the end of the longitudinal study period.

The problem of interpreting the measurement of coronal apposition in a certain cross-section has been discussed. The determination of site locations and accuracy in sectioning could be possible sources of differences between observers. A standardized method of site location was used in this study.

The occurrence of a typical growth curve configuration for each of the study groups (Figure 5) was interpreted as an indication that the generalized influences governing bone growth had been influenced in a particular way for each of the different types of surgical intervention. The importance of circulatory disturbances to bone growth patterns has been discussed in the literature.

Variations in the degree of functional stress loss (Sunden, 1967; Nikitjuk, 1968) would affect the blood distribution. Since the blood supply of portions of the rat mandible is derived from the artery running with the muscle (Huelke and Castelli, 1965), the coronoid, condylar and angular processes would be essentially deprived of a blood supply until a collateral circulation was established. At autopsy, it was discovered that the masseterectomy group had indeed established a significant collateral circulation.

Although the recorded mean weight differences between groups were not statistically significant, the possible role of feeding problems cannot be discounted. Variations in nutrition may have influenced the growth curve patterns of the experimental groups.

The mechanisms responsible for the growth curve configurations, particularly the interesting biphasic response of the masseterectomy group, remain unknown. Further investigation into the change in chemical activities associated with surgical intervention may provide a disclosure of these sophisticated controls.

Examination of the general growth curves supported Schour and Massler (1951) and Baer (1954) in their contention that two periods of growth can be distinguished in the rat. The time of changeover to the second phase was placed at 60 and 20 days, respectively. The age of animals in the

BC period of the present study, where the slope of the normal curve decreases rapidly, was approximately 35 to 40 days.

The purpose of including a sham operation group in the study was to assess the contribution of features such as scar tissue formation, bleeding, facial nerve transection, possible interference with the parotid duct and damage to the temporal fascia in the development of alterations usually ascribed solely to removal of the masseter muscle (Horowitz and Shapiro, 1955; Pratt, 1943). That these features did account for some measure of the observed alterations was indicated by the finding of significant differences in bone apposition between sham operation and normal groups. The sham group experienced early rate declines but showed a recovery phase and usually achieved total growth not significantly different from normal.

It is difficult to draw a general conclusion when comparing the intensity of disturbance in the masseterectomy and extraction groups. At some sites, the masseterectomy group showed the slowest growth while at other sites the extraction group was most affected. On the majority of occasions the measured difference between these two groups was of reasonable magnitude but did not demonstrate statistical significance. Both masseterectomy and extraction groups were affected more than the sham group. This was an expected conclusion.

Mandible

The lower incisor occupies a large portion of many of the mandibular cross-sections. It erupts continuously and is probably a dominant factor in the determination of growth of the body of the mandible. Throughout the study, it was found that significant incremental differences between operated and unoperated sides indicated the presence of a localized, specific effect directly due to the unilateral feature of the surgical intervention. By way of explanation, significant side differences were found in sites related to the incisor in the Symphyseal and Post Symphyseal Region.

Normally, inferior drift of the incisors occurs 2½ times faster than buccal drift to accomodate the reducing curvature of the incisor with anteroposterior eruption and its greater increase in height than width. In the masseterectomy group, decreased inferior drift corresponded to the gross observation of a more pronounced incisal curvature and slower eruption rate of the incisor on the right side (Sites 2 and 3). Further support for these adjustments is provided by the growth of Sites 1 and 4. This growth alteration functions to combat the deviation of the incisors to the right side established by a shift in mandibular orientation immediately following masseterectomy (Horowitz and Shapiro, 1955). The extraction group demonstrated another mechanism for diminishing the possible incisor deviation due to unilateral function loss. The buccal drift adjustment occurred later since the shift in mandibular orientation in the cross-sectional plane was more gradual. The final amounts of buccal drift were not significantly different for the two groups.

The impressive increase in inferior drift of the extraction group was also not an immediate reaction and was likely an adaptation to the altered mandibular position (closed bite). As expected, the gross specimen showed a normal or lessened incisal curvature. Possibly the incisor growth rate was increased in response to demands produced by the loss of molar teeth. This contention brings to mind that the extraction group rates showed less weight deficiency than did the masseterectomy animals, and therefore may have been better nourished.

Examination of the lingual surface growth curves (Figures 26, 27 and 28) revealed that the unoperated sides grew faster. Such a finding is in agreement with, and further support for, the tendency for bone apposition to accomodate for discrepancies produced by translatory shifting of the mandible due to the functional intervention. The lingual surface in the Retromolar Region did not share the pattern (Figure 29) probably because its location was quite near the inferior border and it is also the region where the body of the mandible is created by large amounts of apposition. A similar case applied to Site 27 (Figure 37).

One of the older tenants of the relationship of form and function stated that a decrease in(or loss of) muscle function would result in a decrease in the growth rate of the bone forming the muscle attachment. A consequent diminution in size is an accepted observation supported by numerous investigations cited in the literature review.

A pattern of altered growth direction and a dramatic increase in growth rate was observed at muscle attachments on the operated side of the masseterectomy group. The details of this mechanism, which ends in the "burying" of the muscle attachment in newly formed bone, were given in the result section.

Conversally, the probable increase in functional stress at attachments for the external pterygoid and suprahyoid muscles (digastric) did not show an increase in growth rates (Figure 38).

The inferior border sites detail the development of the antegonial notch by differential apposition rather than by resorption as in the human. The growth differences between left and right sides account for the diminished concavity of the antegonial notch seen on the operated side of the masseterectomy group.

The general growth curve for the normal group is markedly curved from A to C. After the third stain, the approximation to linearity is good. This would explain Jacobson's (1969) finding of correlation between growth sites on the inferior border of the mandible only after the third stain line. It is unlikely that the suggestion, that an influencing factor (the lower incisor) only begins to have effect after 5 weeks of age, is valid. The test of correlation co-efficients is inappropriate for the entire experimental period as it is a test for linearity.

Alveolar process bone deposition was dramatically increased on the operated side of the extraction group. This finding agrees with reports of over-eruption of unopposed teeth. Growth rates were not the same on buccal and lingual sides. The greater lingual apposition rate was deemed necessary to keep the lingually inclined molars erupting vertically.

The third molar is in the process of erupting into occlusion at about 40 days of age which may account for the greater increase in alveolar bone as compared with first molar measurements. A finding by Shiere and Manly (1952) that masticatory efficiency does not reach its peak until a certain tooth has been in the mouth for some time is also of interest in this regard.

Horowitz and Shapiro (1955) found greater degeneration of the alveolar process on the operated side. This could not be substantiated in the present study since the retardation occurred on both sides to the same extent.

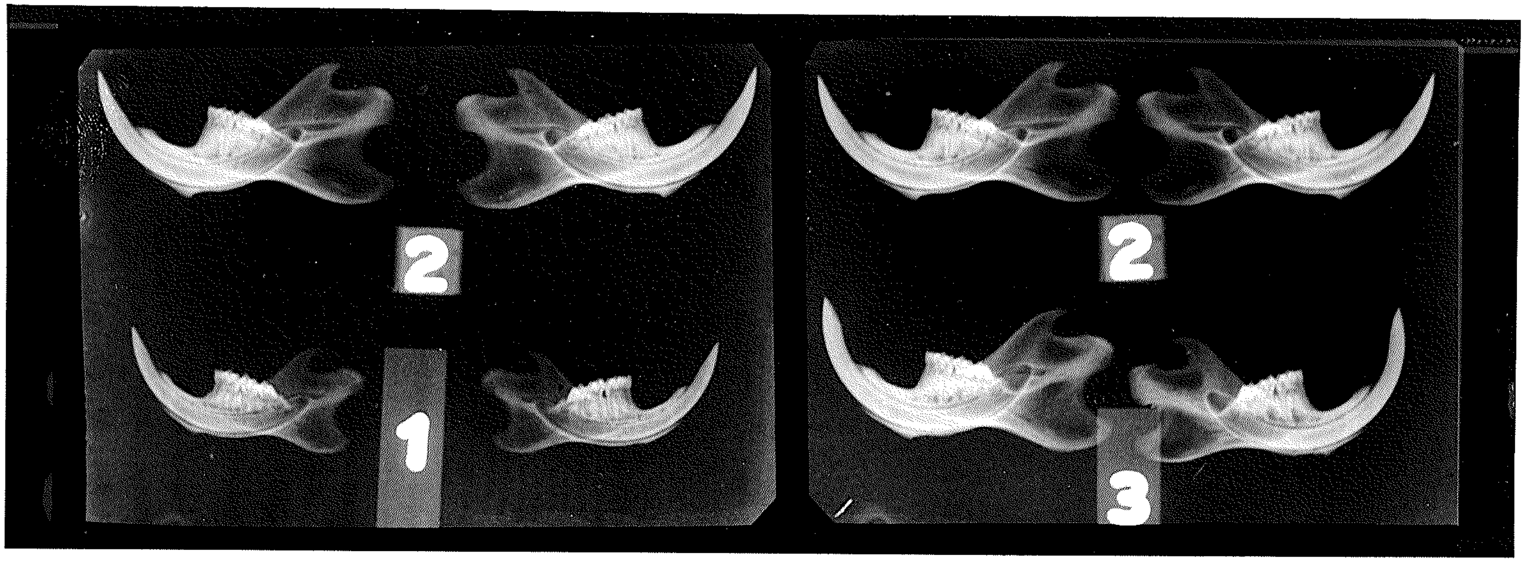
Dentin formation curves manifested a growth pattern distinct from the skeletal pattern. The reduction in dentin formation of the extraction group was shown not to be a function of the older starting age of these animals. A discussion of these findings is found with the results.

Contrary to the mode of development of the human mandible there are <u>two</u> directions of area relocation in the rat mandible. The well documented length increase by backward growth of the ramus region and the consequent area relocation of this portion into more anterior structures was illustrated by the Retromolar Region (Site 25) In the Symphyseal Region, apposition in an anterior direction was associated with continuing incisor eruption. The structures in the Symphyseal Region were consequently relocated toward the future Post Symphyseal Region. It would be assumed that a relatively "stationary" area could be located somewhere between these two independent relocation occurrences. The examination of stain line patterns in the Post Symphyseal Region revealed that this area was undergoing the least remodelling (i.e., relocation). It was interesting to note the proximity of the mental foramen to the proposed area of least relocation.

The pattern of trabeculation of the mandible for the operated side of the masseterectomy group showed the immature design illustrated by a young member of the extraction group in Figure 76. This observation compares with the findings of Horowitz and Shapiro (1951). The loss of functional stress is related to a lack of maturation of the tubecular bone pattern.

Cranium

The most emphasized sequal of the unilateral masseterectomy procedure is the finding of deviation of the rostrum towards the unoperated side. The literature review sites a number of references that support this observation. The degree of asymmetry determined by subjective evaluation of the gross specimen was considerably less than that illustrated by other observers. Examination of the gross specimen in the coronal plane revealed a "torqueing" of the entire nasopremaxillary complex so that the tips of the maxillary incisors deviated to the right.

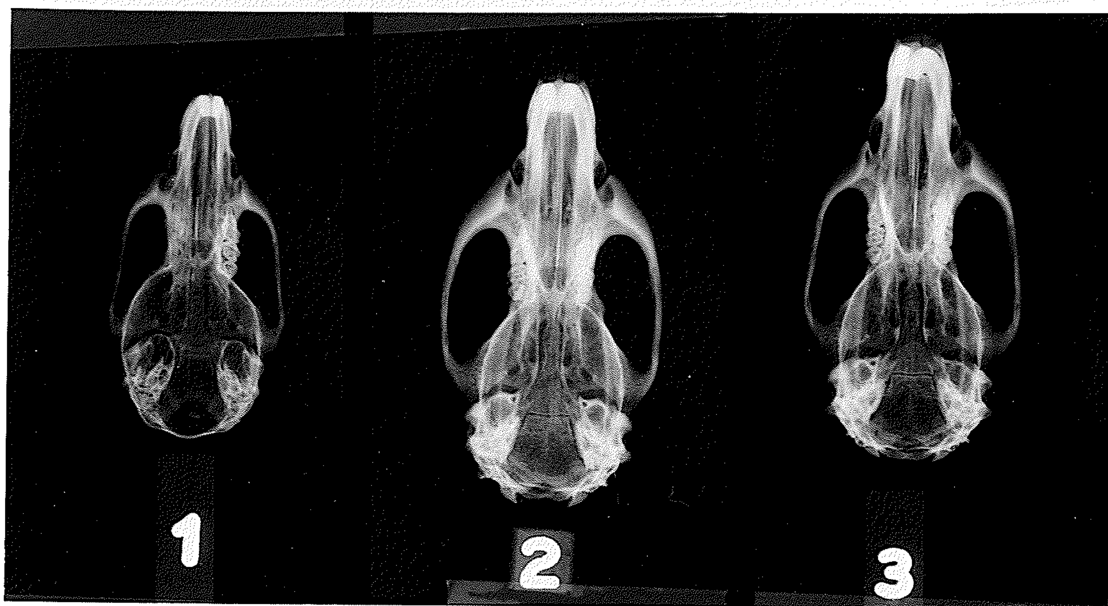


1. Extraction Group (young age)
2. Control Group
3. Masseterectomy Group

Figure 76. Patterns of Trabeculation of the Mandible. Operated sides are on the right.

The nasofrontal suture was seen to be the adjustment site for this alteration which is the result of the unopposed pull of the anterior portion of the left masseter muscle. A minimal amount of deviation in the lateral plane was observed. It was often difficult to subjectively evaluate the extent and direction of the lateral deviation due to the optical illusions resulting from viewing the convex dorsal surface. The position of the temporal ridges also tends to affect the judgement of alignment of cranial vault and snout. These difficulties were shared with other observers. It was, therefore, necessary to use an objective method of evaluation of asymmetry. The almost symmetrical appearances of the crania in Fig. 77 emphasizes the problem. The incisors of the masseterectomy animal can be seen to be deviated to the right.

The nasal cavity manifested a general form of development marked by external apposition and internal resorption. The increase in width occurred faster than increase in height in the Incisor Region but the opposite was true in the more posterior Premaxillary Region. A decreased rate of vertical development was noted for the extraction group not only at the palatal sites which were directly affected by the molar extractions but also at the dorsal surface sites. Specific events were discussed with the results.



1. Extraction Group (young age)
2. Control Group
3. Masseterectomy Group

Figure 77. Evaluation of Cranial Asymmetry. Operated sides are on the left.

The cranial vault, in contrast to the nasal cavity, showed apposition on the ectocranial as well as endocranial surfaces of the vault. Increases in width were mediated by sutural growth rather than internal resorption. A relocation in the superior direction by apposition on superiorly facing surfaces was contrasted with inferior drift in the nasal cavity regions. The total effect of these two processes is the flattening of the dorsal curvature in the sagittal plane as age progresses. The endocranial and ectocranial sites grew independently. A reversal in relative growth rates was discussed in the results.

The muscle attachments on the cranium behaved similarly to the pattern discussed for the masseteric ridge of the mandible.

SUMMARY AND CONCLUSIONS

A review of opinions regarding the interrelationship of bone form and functional stress mediated through soft tissues revealed numerous disparities in proposed explanations. The difficulties associated with subjective evaluation of gross specimens demonstrating induced aberrations have been cited as a causitive factor in prompting contradictory findings. The value of more reliable assessment methods to investigate the sequelae of unilateral masseterectomy or molar extractions was apparent and the present study utilizing a fluorescence microscopy technique conbined with sequential vital staining was undertaken. The objectives were:

(1) Description of morphological alterations (in the coronal plane) resulting from a change in function by means of the parameters of bone growth rate and direction.

(2) Assessment of the relative contribution of transformation and translation in achieving the altered growth pattern.

(3) Examination of the validity of gross skeletal findings.

(4) Development of general postulates regarding the mechanisms of bone growth alterations.

The subjects were male Long Evans strain rats. Three experimental groups, comprising 30 animals and consisting of an extraction group, a masseterectomy group and a sham muscle operation group were examined and their bone growth measurements (cranium and mandible) were compared with those of a matched control group. A standardized technique involving a sequence of five vital stains, which produced fluorescent bone markings, was used to microscopically assess bone growth increments throughout a 74-day experimental period. Both linear and coordinate analyses were generated.

A total of 30 sites in six cross sections of the mandible and 58 sites in seven coronal sections of the cranium were investigated. Statistical evaluation of growth differences between seven subgroupings was achieved using the Duncan multiple range test for each growth increment studied, after the usual statistics for mean differences had been compiled. Graphical representation of growth rates allowed visualization of important alterations.

Numerous important findings, often at odds with widely accepted postulates, were derived from the mass of quantified data. Some of the deductions that were derived as a consequence of this study follow.

1. Each type of functional alteration is associated with a characteristic bone growth curve configuration that is typical of the majority of growth sites. Systemic or generalized differences are held responsible for the pattern differences.

2. Specific growth curves are associated with sites that were directly affected by the particular mode of surgical intervention. These sites comprise the significant findings as they manifest the adaptive mechanisms and are usually associated with side differences in bone apposition rates. The latter is a consequence of the unilateral feature of the experiments.

3. The mechanism of development of asymmetry is mediated by sutural adjustments. The associated remodelling process tends to reduce the asymmetry rather than produce it. There is a tendency for a maintenance of symmetry demonstrated by the warping of the mandible on the operated side of the masseterectomy animals.

4. The rat mandible develops differently from the human mandible because of the influence of the continually erupting lower incisor. Both anterior and posterior directions of area relocation were revealed. The Post Symphyseal Region undergoes the least area relocation and is associated with

the mental foramen.

5. The removal of the masseter muscle produces an increase in bone apposition at the operated muscle attachments (masseteric ridge) but a change in the direction of bone growth to yield a gradual obliteration of the muscle attachment prominence. An increased rate of growth also occurs on the zygoma of the operated side in contradistinction to the "atrophy" that has been reported. Bone growth occurrences can be better assessed by microscopic inspection.

6. Sites of muscle attachment for unaltered muscles (temporalis and digastric) do not display a growth stimulation due to a greater functional demand. Instead a growth retardation following the non-specific pattern is to be expected.

7. The generalized growth reduction of the masseterectomy and extraction groups show significant differences during certain intervals but similar amounts of total growth.

8. The ectrocranial and endocranial surfaces of the cranial vault grow independently and undergo a reversal in their relative apposition rates as maturation progresses. A superior drifting of the cranial vault associated with an inferior drifting of palate results in a gradual decrease of the sagittal plane kyphosis of the craniofacial complex.

The flattening of the cranial vault in the coronal plane is the result of "hinging" at the sutures (translation of bones), differential rates of apposition at the sutural area and the area of greatest curvature; and increasing prominence of the temporal line. Resorption occurs on the endocranial surface near the midsagittal suture.

9. The decreased amounts of bone growth recorded as a result of functional intervention are associated with a retardation of maturation. Trabecular patterns fail to mature on the operated masseterectomy hemimandible. The growth dominance reversal of ectocranial and endocranial surfaces is retarded and the immature degree of lower incisor curvature is retained in some experimental groups. Such changes are more pronounced on the operated side.

10. Incidental surgical interference, that is not commonly differentiated from the effect of removal of the masseter muscle alone is responsible for a measure of deviation from normal development. Such deviations were commonly not statistically significant. The sham operation group often grow more than normal suggesting that the healing responses to a minimal surgical interference may stimulate growth via a circulatory enhancement. The importance of variables other than those studied is recognized in establishing causative relationships.

11. A longitudinal design utilizing sequential vital staining and fluorescence microscopy as described herein is an effective method of assessing the amount and direction of bone growth. Such information is a prerequisite to hypotheses regarding bone growth alteration.

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APPENDIX I

NORMAL MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.68	0.37	0		2.01	0.15	-0.03	0.06
	2	1.44	0.17	0.34	0.11	1.04	0.14	0.45	0.13
	3(O)	0		0		-0.03	0.03	0.17	0.09
XII	4(O)	0		0		-0.18	0.14	0.03	0.09
	5(D)	1.47	0.24	0		1.51	0.20	0.15	0.15
	6	3.37	0.37	-0.82	0.39	4.01	0.25	-1.05	0.41
	7	2.89	0.31	-1.46	0.40	3.50	0.24	-1.67	0.34
	8	1.85	0.26	-1.85	0.31	1.79	0.31	-2.21	0.16
	9	0.69	0.34	-1.58	0.18	0.62	0.34	-1.73	0.23
XIII	12(D)	3.07	0.19	0		3.79	0.29	0.70	0.20
	13	2.06	0.26	-1.33	0.21	2.24	0.38	-1.49	0.19
	14	0.26	0.19	-2.81	0.23	-0.15	0.42	-3.16	0.24
	15	-0.27	0.38	-1.76	-.34	-0.60	0.22	-1.52	0.29
	16(O)	0		0		-0.52	0.14	0.11	0.12
	17	1.18	0.29	1.13	0.21	1.09	0.29	1.23	0.23
	18	3.08	0.36	2.02	0.38	3.70	0.27	2.50	0.33
XIV	19(D)	3.54	1.20	0		4.45	1.21	0.32	0.21
	20	2.69	1.16	-0.39	0.13	2.88	1.15	-0.64	0.16
	21	0.75	0.22	-1.59	-.52	0.49	1.04	-2.00	0.49
	22(O)	0		0		-0.35	1.26	0.12	0.42
	23	1.67	1.42	1.00	0.28	1.53	1.46	1.16	0.32
XV	24	3.02	0.62	1.14	1.14	3.69	0.52	1.09	1.35
	25(D)	0.69	0.08	0		0.85	0.14	-0.38	0.15
	26(O)	0		0		-0.23	0.06	-0.13	0.11
	27	0.31	0.30	0.69	0.09	0.14	0.41	0.99	0.15
XVI	28	4.38	0.45	-1.05	0.16	5.12	0.52	-0.77	0.37
	29(D)	2.48	0.75	-0.29	0.01	3.01	0.60	0	
	30(O)	0.39	0.23	-0.21		0		0	

O Point of origin.
D Point of X direction.

APPENDIX II

OPERATED SIDE MASSETERECTOMY MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.58	0.33	0		1.82	0.32	-0.03	0.06
	2	1.30	0.29	-0.12	0.32	1.17	0.30	-0.25	0.32
	3(O)	0		0		0.01	0.06	-0.15	0.06
XII	4(O)	0		0		-0.14	0.05	-0.08	0.03
	5(D)	1.60	0.14	0		1.62	0.15	-0.06	0.06
	6	3.36	0.25	0.66	0.31	3.93	0.32	0.88	0.31
	7					3.25	0.19	1.63	0.27
	8	1.75	0.26	1.75	0.11	1.69	0.26	2.09	0.15
	9	0.76	0.24	1.45	0.13	0.67	0.25	1.63	0.15
XIII	10	4.95	0.49	-1.45	0.49	4.72	0.49	-1.48	0.45
	11	4.45	0.34	-1.13	0.34	4.38	0.32	-1.31	0.34
	12(D)	3.16	0.34	0		3.72	0.26	-0.46	0.17
	13	2.06	0.42	1.13	0.21	2.20	0.44	1.25	0.20
	14	-0.13	0.01	2.55	0.06	-0.77	0.48	2.58	0.42
	15	-0.36	0.38	1.38	0.37	-0.68	0.36	1.28	0.38
	16(O)	0		0		-0.38	0.38	0.01	0.33
	17	1.98	0.60	-1.73	0.27	1.94	0.76	-1.89	0.35
	18	3.06	0.48	-1.95	0.17	3.42	0.67	-2.29	0.29
XIV	19(O)	0		0		-0.57	0.11	-0.06	0.13
	20	0.57	0.16	-0.10	0.08	0.53	0.15	-0.28	0.09
	21	2.68	0.11	-1.26	0.24	3.06	0.18	-1.62	0.19
	22(D)	3.25	0.13	0		3.87	0.21	-0.63	0.19
	23	1.28	0.38	1.72	0.21	1.37	0.39	1.85	0.21
XV	24	4.09	0.10	-1.10	0.69	4.38	0.46	-1.03	0.66
	25(D)	0.63	0.08	0		0.81	0.11	0.32	0.10
	26(O)	0		0		-0.20	0.07	0.13	0.09
	27	0.30	0.16	-0.56	0.35	0.23	0.20	-0.70	0.34
XVI	28	4.48	0.63	1.02	0.15	4.63	0.64	0.73	0.15
	29(D)	1.97	0.23	0.15	0.05	2.75	0.73	0	
	30(O)	0.28	0.15	0.14	0.12	0		0	

O Point of origin.
D Point of X direction.

APPENDIX III

UNOPERATED SIDE MASSETERECTOMY MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.46	0.18	0		1.69	0.15	0.02	0.09
	2	1.26	0.17	0.14	0.11	1.07	0.14	0.30	0.06
	3	0		0		0	0.03	0.11	0.06
XII	4(O)	0		0		-0.14	0.06	0.08	0.04
	5(D)	1.63	0.16	0		1.66	0.15	0.14	0.05
	6	3.56	0.12	-0.50	0.07	4.35	0.21	-0.53	0.17
	7					3.55	0.17	-1.50	0.11
	8	1.99	0.21	-1.70	0.06	1.99	0.25	-2.07	0.10
	9	1.00	0.20	-1.60	0.10	0.93	0.20	-1.76	0.09
XIII	10	4.83	0.31	1.57	0.27	4.58	0.28	1.59	0.25
	11	4.34	0.25	1.26	0.22	4.23	0.26	1.42	0.23
	12(D)	3.08	0.24	0		3.65	0.21	0.49	0.13
	13	2.14	0.27	-1.15	0.26	2.29	0.28	-1.28	0.27
	14	-0.25	0.53	-2.41	0.33	-0.55	0.42	-2.89	0.27
	15	-0.30	0.24	-1.61	0.26	-0.63	0.21	-1.56	0.27
	16(O)	0		0		-0.25	0.12	0.08	0.06
	17	1.79	0.41	1.59	0.39	1.71	0.42	1.67	0.38
	18	3.17	0.24	2.16	0.31	3.53	0.26	2.50	0.32
XIV	19(O)	0		0		-0.60	0.19	-0.15	0.11
	20	0.72	0.18	0.12	0.18	0.64	0.17	0.35	0.17
	21	2.75	0.02	1.36	0.19	3.11	0.18	1.80	0.22
	22(D)	3.40	0.11	0		4.07	0.22	-0.16	0.08
	23	1.54	0.13	-1.65	0.24	1.60	0.15	-1.75	0.20
XV	24	3.54	0.65	1.68	1.25	4.33	0.58	1.24	0.83
	25(D)	0.65	0.10	0		0.83	0.15	-0.33	0.11
	26(O)	0		0		-0.20	0.05	-0.10	0.08
	27	0.31	0.35	0.67	0.28	0.23	0.28	0.90	0.18
XVI	28	4.66	0.54	-0.97	0.19	4.79	0.54	-0.71	0.17
	29(D)	2.95	0.62	-0.19	0.04	2.97	0.56	0	
	30(O)	0.21	0.07	-0.16	0.05	0		0	

O Point of origin.
D Point of X direction.

APPENDIX IV

OPERATED SIDE SHAM MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.64	0.18	0		1.95	0.16	-0.10	0.74
	2	1.31	0.26	-0.23	0.11	1.07	0.16	-0.39	0.10
	3(O)	0		0		0.01	0.05	-0.14	0.08
XII	4	0		0		-0.12	0.04	-0.09	0.06
	5(D)	1.60	0.19	0		1.69	0.20	-0.13	0.07
	6	3.48	0.20	0.64	0.16	4.23	0.31	0.77	0.21
	7	2.88	0.15	1.09	0.09	3.41	0.19	1.55	0.15
	8	1.81	0.23	1.69	0.07	1.85	0.27	2.08	0.11
	9	0.84	0.20	1.49	0.12	0.77	0.21	1.71	0.12
XIII	10	4.78	0.51	-1.72	0.27	4.53	0.57	-1.78	0.27
	11	4.43	0.47	1.49	0.29	4.39	0.45	-1.69	0.29
	12(D)	2.95	0.34	0		3.64	0.42	-0.71	0.26
	13	1.90	0.42	1.45	0.37	2.05	0.45	1.55	0.39
	14	-0.41	0.32	2.65	0.17	-0.76	0.32	2.94	0.17
	15	-0.37	0.24	1.69	0.13	-0.73	0.21	1.62	0.16
	16(O)	0		0		-0.30	0.13	-0.06	0.06
	17	1.46	0.34	-1.41	0.26	1.42	0.38	-1.51	0.26
	18	2.87	0.45	-2.04	0.24	3.63	0.43	-2.59	0.31
XIV	19(O)	0		0		-0.86	0.15	0.20	0.17
	20	0.64	0.16	-0.16	0.21	0.56	0.14	-0.40	0.19
	21	2.83	0.15	-1.27	0.38	3.00	0.14	-1.77	0.49
	22(D)	3.27	0.14	0		3.91	0.17	0.17	0.13
	23	1.36	0.73	1.45	0.56	1.17	0.61	1.83	0.55
XV	24	3.01	0.24	-2.45	0.11	4.56	0.68	-1.09	0.78
	25(D)	0.69	0.11	0		0.86	0.14	0.38	0.11
	26(O)	0		0		-0.16	0.05	0.07	0.07
	27	0.37	0.19	-0.69	0.07	0.25	0.25	-0.87	0.13
XVI	28	4.74	0.78	0.98	0.30	5.39	0.98	0.90	0.28
	29(D)	2.53	0.50	0.17	0.02	3.13	0.68	0	
	30(O)	0.22	0.08	0.04	0.11	0		0	

O Point of origin.
D Point of X direction.

APPENDIX V

UNOPERATED SIDE SHAM MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.44	0.25	0		1.78	0.32	0.03	0.10
	2	1.21	0.25	0.13	0.13	0.96	0.13	0.34	0.12
	3(O)	0		0		0	0.03	0.10	0.10
XII	4(O)	0		0		-0.13	0.05	0.11	0.04
	5(D)	1.56	0.08	0		1.60	0.06	0.13	0.05
	6	3.41	0.20	-0.48	0.24	4.19	0.26	-0.52	0.23
	7	2.86	0	-1.44	0	3.32	0.13	-1.51	0.21
	8	1.80	0.17	-1.65	0.13	1.80	0.25	-1.97	0.09
	9	0.87	0.14	-1.46	0.09	0.81	0.11	-1.66	0.04
XIII	10	4.74	0.33	1.69	0.26	4.54	0.32	1.74	0.27
	11	4.33	0.33	1.42	0.28	4.29	0.28	1.59	0.33
	12(D)	2.93	0.22	0		3.64	0.29	0.64	0.13
	13	1.91	0.35	-1.40	0.37	2.06	0.36	-1.53	0.39
	14	-0.43	0.38	-2.68	0.12	-0.90	0.50	-2.95	0.13
	15	-0.41	0.30	-1.64	0.15	-0.79	0.31	-1.55	0.17
	16(O)	0		0		-0.20	0.09	0.08	0.05
	17	1.58	0.23	1.39	0.33	1.53	0.25	1.48	0.34
	18	2.94	0.19	1.98	0.31	3.59	0.21	2.45	0.40
XIV	19(D)	0		0		-0.83	0.15	-0.13	0.11
	20	0.62	0.18	0.17	0.09	0.54	0.16	0.37	0.10
	21	2.76	0.05	1.24	0.06	3.08	0.16	1.71	0.21
	22(D)	3.27	0.11	0		4.05	0.23	-0.25	0.13
	23	1.33	0.33	-1.61	0.17	1.39	0.31	-1.76	0.20
XV	24	4.00	0	1.00	0	4.50	0.16	1.20	0.78
	25(D)	0.76	0.08	0		0.92	0.09	-0.37	0.09
	26(O)	0		0		-0.14	0.08	-0.10	0.05
	27	0.45	0.11	0.68	0.08	0.27	0.19	0.98	0.16
XVI	28	4.98	0.52	-1.07	0.15	5.34	0.69	-0.86	0.13
	29(D)	2.63	0	-0.22	0	3.14	0.55	0	
	30(O)	0.19	0.03	-0.09	0.03	0		0	

O Point of origin
D Point of X direction

APPENDIX VI

OPERATED SIDE EXTRACTION MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.75	0.21	0		2.06	0.37	-0.03	0.18
	2	1.62	0.16	-0.10	0.19	1.38	0.32	-0.34	0.17
	3(O)	0		0		0.03	0.03	-0.16	0.05
XII	4(O)	0		0		-0.13	0.05	-0.11	0.05
	5(D)	1.86	0.14	0		1.90	0.16	-0.09	0.01
	6	3.70	0.22	0.67	0.28	4.15	0.34	0.80	0.33
	7					3.37	0.37	1.70	0.29
	8	1.99	0.24	1.91	0.16	1.97	0.22	2.21	0.10
	9	1.13	0.39	1.73	0.15	1.07	0.37	1.87	0.10
XIII	10	6.14	0.88	-1.68	0.35	5.37	1.01	-1.63	0.38
	11	5.75	0.76	-1.46	0.35	5.42	0.94	-1.43	0.33
	12(D)	3.58	0.17	0		4.48	0.56	-0.59	0.35
	13	2.36	0.23	1.29	0.24	2.49	0.23	1.40	0.20
	14	-0.11	0.30	2.63	0.38	-0.32	0.52	2.85	0.27
	15	-0.16	0.16	1.44	0.29	-0.37	0.16	1.48	0.25
	16(O)	0		0		-0.18	0.07	-0.06	0.04
	17	1.69	0.41	-1.30	0.30	1.69	0.42	-1.31	0.30
	18	3.62	0.38	-2.17	0.11	4.71	0.76	-2.38	0.16
XIV	19(O)	0		0		-1.26	0.25	0.21	0.28
	20	0.89	0.32	-0.42	0.25	0.83	0.29	-0.55	0.25
	21	3.25	0.22	-1.61	0.42	3.50	0.24	0.01	0.35
	22(D)	3.78	0.29	0		4.21	0.27	0.15	0.08
	23	1.81	0.36	1.21	0.37	1.75	0.56	1.40	0.28
XV	24					4.36	0.55	-2.10	1.08
	25(D)	0.77	0.11	0		0.95	0.13	0.25	0.09
	26(O)	0		0		-0.08	0.06	0.09	0.08
	27	0.23	0.24	-0.71	0.29	0.08	0.30	-0.89	0.26
XVI	28								
	29								
	30(O)	0.17	0	0.10	0	0		0	

O Point of origin.
D Point of X direction.

APPENDIX VII

UNOPERATED SIDE EXTRACTION MANDIBLE

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
XI	1(D)	1.78	0.13	0		2.10	0.13	0.02	0.06
	2	1.67	0.21	0.15	0.10	1.21	0.14	0.37	0.10
	3(O)	0		0		-0.01	0.03	0.10	0
XII	4(O)	0		0		-0.12	0.04	0.10	0.04
	5(D)	1.77	0.13	0		1.83	0.15	0.12	0.04
	6	3.75	0.19	-0.62	0.20	4.26	0.21	-0.73	0.27
	7					3.53	0.24	-1.63	0.22
	8	1.99	0.23	-1.93	0.19	1.99	0.21	-2.11	0.14
	9	0.90	0.14	-1.65	0.09	0.85	0.16	-1.82	0.07
XIII	10	5.51	0.38	1.59	0.13	5.33	0.08	1.67	0.14
	11	5.09	0.27	1.37	0.17	5.09	0.26	1.52	0.17
	12(D)	3.63	0.21	0		4.32	0.34	0.61	0.30
	13	2.33	0.27	-1.40	0.22	2.49	0.31	-1.56	0.22
	14	-0.12	0.22	-2.44	0.13	-0.51	0.25	-2.83	0.21
	15	-0.17	0.24	-1.62	0.18	-0.38	0.30	-1.59	0.18
	16(O)	0		0		-0.09	0.18	0.06	0.09
	17	1.69	0.24	1.23	0.15	1.66	0.22	1.26	0.15
	18	3.57	0.36	2.09	0.18	4.29	0.32	2.50	0.22
XIV	19(O)	0		0		-0.83	0.11	-0.21	0.11
	20	0.93	0.10	0.38	0.16	0.81	0.09	0.63	0.18
	21	3.22	0.13	1.44	0.38	3.38	0.16	1.95	0.29
	22(D)	3.74	0.13	0		4.24	0.11	-0.19	0.14
	23	1.73	0.28	-1.47	0.30	1.79	0.29	-1.55	0.35
XV	24	2.69	0	2.97	0	4.69	0.58	1.22	1.49
	25(D)	0.72	0.09	0		0.88	0.08	-0.24	0.09
	26(O)	0		0		-0.13	0.08	-0.08	0.07
	27	0.27	0.28	0.71	0.10	0.19	0.33	0.92	0.15
XVI	28	5.39	0.48	-1.08	0.21	5.60	0.58	-0.95	0.21
	29(O)	3.38	0.24	-0.10	0.09	3.45	0.20	0	
	30(O)					0		0	

O Point of origin.
D Point of X direction.

APPENDIX VIII

NORMAL CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1(O)	0	0.01	0.13	0.06	0		0	
	2	0.89	0.32	1.06	0.14	1.00	0.28	1.15	0.26
	3	4.20	0.68	2.91	0.44	4.29	0.46	3.30	0.26
	4	8.20	0	1.90	0	7.45	0.48	2.37	0.35
	5	8.03	0.36	0.67	0.14	8.11	0.44	0.64	0.13
	6(D)	7.67	0.39	0.23	0.09	7.77	0.47	0	
II	7(O)	0	0.02	0.19	0.09	0		0	
	8	-0.32	0.21	0.94	0.83	-0.57	0.25	0.93	0.84
	9	6.06	0.54	2.76	1.49	6.39	0.66	3.49	1.83
	10	7.37	0.36	2.33	0.16	7.30	0.39	2.33	1.30
	11	7.85	0.44	2.09	0.24	8.17	0.48	1.87	1.10
	12	8.13	0.36	0.49	0.29	8.37	0.38	0.50	0.29
	13(D)	7.92	0.48	0.13	0.12	7.93	0.47	0	
III	14'					0.76	0.16	-1.95	0.89
	14(O)	0.39	0.08	0.12	0.07	0		0	
	15	0.50	0.19	2.13	0.37	0.28	0.22	2.10	0.38
	16	2.41	0.45	4.08	0.30	2.33	0.48	4.22	0.26
	17	4.30	0.40	5.71	0.41	5.17	0.56	7.13	0.43
	18					8.34	0.43	4.56	0.49
	19					10.82	0.34	2.29	0.44
	20					10.49	0.38	1.81	0.43
	21	11.38	0	2.38	0	11.12	0.45	0.94	0.39
	21'(D)	10.71	1.01	0.86	0.07	11.06	0.36	0	
IV	22'(O)					0		0	
	22	0.15	0.45	-1.83	1.08	-0.32	0.18	-1.83	1.05
	23	1.87	0.24	-4.06	2.64	1.86	0.33	-4.31	2.43
	24	6.75	0.66	-3.93	0.22	6.33	0.53	-3.41	1.84
	25	10.76	0.44	-2.93	0.50	11.32	1.22	-2.70	1.53
	26	11.19	0.31	-1.67	0.66	11.70	0.40	-1.51	0.71
	27(D)	10.50	0	-0.20	0	10.72	0.51	0	
	28	10.45	0.64	-1.36	0.21	10.66	0.41	-1.05	0.60
	29					7.00	1.38	-0.49	0.34

(Continued)

APPENDIX VIII (CONTINUED)

Region	Site	ORIGINAL X	SD	Y	SD	FINAL X	SD	Y	SD
V	30					-2.60	0.86	10.34	0.53
	31	-2.68	0	9.88	0	-4.27	0.43	12.37	0.49
	32	-4.96	0	0.98	0	-1.01	0.33	-0.67	1.17
	33(O)	-0.62	0	-0.87	0	0		0	
	34	6.55	0.47	4.68	0.33	7.44	0.46	4.92	0.40
	35	8.15	0.68	2.14	0.44	8.30	0.61	2.20	0.46
	36	7.45	0.67	1.90	0.60	7.25	0.63	1.82	0.53
	37(D)	8.13	0.41	0.09	0.02	8.50	0.58	0	
VI	38	-1.33	0.23	0.09	0.12	-1.13	0.40	-0.28	1.43
	39(O)					0		0	
	40	-2.33	0.16	-1.70	0.61	-1.80	0.70	-0.33	4.35
	41	-1.22	0.27	-2.65	0.46	-0.70	0.46	-1.29	3.36
	42	2.24	2.70	-5.38	5.21	2.40	2.45	-5.65	4.75
	43	1.68	1.15	-7.58	6.70	0.70	3.19	-8.07	6.78
	44	2.90	3.35	-6.28	5.88	3.04	3.07	-6.68	5.39
	45	7.70	3.59	-4.84	3.26	7.98	3.57	-4.87	3.21
	46	7.18	3.25	-4.43	3.08	7.07	3.22	-4.42	3.10
	47	8.52	3.19	-2.77	1.86	8.91	3.07	-2.82	1.86
	48	8.21	2.95	-2.68	1.92	8.09	2.83	-2.66	1.89
	49(D)	10.04	0.24	-0.30	0.10	9.04	2.26	0	
VII	50(O)	0.13	0.06	-0.17	0.14	0		0	
	51	-0.65	2.21	-3.66	2.56	-0.86	2.14	-3.73	2.46
	52	3.59	2.79	-5.97	1.55	3.06	3.33	-5.94	1.45
	53	4.94	1.89	-6.35	0.73	5.30	2.48	-6.94	0.89
	54	9.76	2.37	-5.10	0.51	9.57	1.67	-4.93	0.46
	55	10.27	0.28	-5.36	0.40	10.29	1.84	-5.75	0.32
	56	11.49	1.42	-2.88	0.57	11.28	1.35	-2.89	0.55
	57	12.24	0.65	-3.15	0.82	12.09	1.37	-3.28	0.63
	58(D)	13.38	0.55	-0.26	0.24	12.79	0.98	0	

O Point of origin.
D Point of X direction.

APPENDIX IX

OPERATED SIDE MASSETERECTOMY CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE
STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1(O)	0	0.01	0.08	0.04	0		0	
	2	1.01	0.38	0.58	0.06	1.06	0.32	0.66	0.06
	3	4.44	0.65	2.33	0.40	4.34	0.58	2.71	0.13
	4	7.02	0.57	1.39	0.13	7.17	0.61	1.50	0.15
	5	7.31	0.54	0.15	0.07	7.43	0.55	0.15	0.08
	6(D)	7.11	0.55	0.10	0	7.11	0.55	0	
II	7(O)	0.01	0.01	0.12	0.04	0		0	
	8	-0.10	0.11	1.22	0.08	-0.21	0.09	1.24	0.09
	9	6.06	0.48	2.33	0.36	6.92	0.56	2.92	0.24
	10	7.10	0.42	1.67	0.07	7.05	0.43	1.84	0.12
	11	7.35	0.42	1.66	0.09	7.65	0.45	1.72	0.10
	12	7.55	0.49	0.09	0.09	7.71	0.43	0.08	0.09
	13(D)	7.19	0.40	0.04	0.70	7.19	0.41	0	
III	*14'					0.15	0.17	-1.55	0.07
	14(O)	0.25	0.09	0.16	0.05	0		0	
	15	0.32	0.09	1.79	0.20	0.18	0.11	1.85	0.19
	16	2.42	0.12	3.99	0.28	2.34	0.20	4.09	0.28
	17	3.96	0.20	5.29	0.24	4.82	0.34	6.43	0.37
	18					7.06	0.38	4.63	0.40
	19					9.93	0.44	1.64	0.17
	20	8.96	0.31	1.11	0.02	9.57	0.41	1.22	0.13
	21	9.39	0.44	0.73	0.08	10.00	0.46	0.65	0.11
	*21'(D)					9.64	0.41	0	
IV	*22'(O)					0		0	
	22	0.23	0.11	1.60	0.13	-0.30	0.10	1.60	0.12
	23	1.33	0.24	3.90	0.14	1.41	0.23	4.11	0.24
	24	5.62	0.14	2.80	0.23	5.64	0.38	2.98	0.13
	25	10.20	0.37	2.24	0.12	10.56	0.38	2.31	0.13
	26	10.27	0.34	1.46	0.24	10.64	0.37	1.41	0.25
	27(D)	9.91	0.29	0.04	0.06	9.78	0.32	0	
	28	9.53	0	1.10	0	9.60	0.31	1.40	0.27
	29	6.05	0.46	-0.37	0.55	6.12	0.35	-0.15	0.35

(Continued)

APPENDIX IX (CONTINUED)

Region	Site	ORIGINAL X	SD	Y	SD	FINAL X	SD	Y	SD
IV	*27'					1.93	0.47	9.95	0.30
	*28'					2.91	0.56	9.88	0.37
	*29'					3.64	0.67	9.59	0.46
V	30					-0.18	0.19	10.76	0.53
	31					-2.36	0.37	3.43	0.40
	32(O)	0.14	0.05	0	0.01	0		0	
	33	0.65	0.10	0.45	0.08	0.63	0.07	0.47	0.14
	34	7.41	0.30	4.70	0.33	8.33	0.39	4.71	0.23
	35	8.80	0.18	2.15	0.33	8.81	0.26	2.12	0.32
	36	8.47	0.36	2.06	0.37	8.35	0.36	2.06	0.36
	37(D)	8.85	0.19	0.04	0.05	8.63	0.32	0	
	*37'					-2.37	0.16	0.06	0.07
VI	38	-1.30	0.15	0.02	0.10	-1.13	0.16	0.01	0.11
	39(O)	-0.30	0.14	0.01	0.01	0		0	
	40	-1.66	0	1.74	0	-1.58	0.24	1.76	0.32
	41	-0.97	0.19	2.03	0.19	-0.80	0.41	2.05	0.38
	42	3.49	0.32	7.46	0.21	3.55	0.25	7.35	0.23
	43	2.43	0.66	9.71	0.36	1.91	0.68	10.42	0.42
	44	4.00	0.33	7.97	0.12	4.05	0.37	8.07	0.14
	45	8.35	0.38	5.52	0.34	8.52	0.49	5.61	0.33
	46	8.17	0.41	5.40	0.30	8.10	0.42	5.36	0.33
	47	9.33	0.34	2.71	0.40	9.48	0.39	2.72	0.39
	48	9.18	0.35	2.58	0.19	9.09	0.34	2.58	0.19
	49(D)	9.27	0.52	0.05	0.07	9.30	0.37	0	
	50	-0.43	0.21	3.27	0.41	-0.61	0.21	3.09	0.47
	51	-0.86	0.47	6.22	0.43	-0.97	0.55	6.36	0.46
	52	3.74	0.39	7.65	0.27	3.83	0.34	7.75	0.25
	53	5.93	0.14	7.86	0.02	6.10	0.47	7.83	0.43
	54	9.55	0.55	5.51	0.51	9.48	0.50	5.42	0.51
	55	9.51	0.69	5.86	0.26	9.88	0.60	5.79	0.45
	56	10.91	0.41	2.87	0.60	10.81	0.40	2.86	0.62
	57	11.06	0.35	2.95	0.68	11.13	0.43	2.91	0.60
	58(D)	10.85	0.17	0.01	0.02	11.02	0.41	0	
	*58'(O)					0		0	

O Point of origin.
D Point of X direction.
* Prime numbered sites not included in linear analysis.

APPENDIX X

UNOPERATED SIDE MASSETERECTOMY CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1	0	0.01	-0.16	0.07	0	0.01	-0.08	0.08
	2	0.96	0.36	-0.66	0.15	1.01	0.31	-0.72	0.11
	3	4.22	0.43	-2.35	0.56	4.28	0.39	-2.76	0.15
	4	6.94	0.49	-1.51	0.09	7.06	0.54	-1.62	0.13
	5	7.33	0.54	-0.31	0.09	7.44	0.54	-0.30	0.09
	6	7.13	0.54	-0.27	0.07	7.13	0.55	-0.12	0.06
II	7	0.03	0.06	-0.17	0.05	0.37	0.07	-0.06	0.05
	8	-0.07	0.11	-1.32	0.17	-0.19	0.10	-1.35	0.17
	9	6.09	0.50	-2.50	0.18	7.07	0.67	-2.95	0.23
	10	7.10	0.46	-1.74	0.09	7.05	0.46	-1.94	0.10
	11	7.29	0.44	-1.74	0.14	7.62	0.53	-1.77	0.16
	12	7.49	0.41	-0.17	0.06	7.70	0.42	-0.18	0.07
	13	7.19	0.40	-0.16	0.07	7.19	0.40	-0.09	0.06
III	*14'	0.37	0.20	-1.71	0.11	0.18	0.15	-1.76	0.10
	14	0.84	0.14	-3.37	0.15	0.49	0.13	-3.34	0.17
	15	1.55	0.28	-4.94	0.30	1.42	0.29	-5.06	0.29
	16	4.31	0.22	-6.19	0.52	4.39	0.31	-6.35	0.46
	17	6.06	0.20	-6.90	0.41	7.14	0.46	-7.65	0.63
	18	0		0		8.75	0.36	-5.25	0.47
	19	9.26	0	-1.63	0	10.52	0.46	-1.65	0.36
	20	9.63	0	-0.96	0	10.02	0.43	-1.29	0.17
	21	9.64	0.46	-0.60	0.13	10.24	0.47	-0.65	0.11
	*21'	0		0		9.62	0.37	-0.06	0.06
IV	*22'	0		0		-0.01	0.03	-0.02	0.09
	22	0.16	0.17	-1.83	0.19	-0.16	0.36	-1.84	0.15
	23	1.43	0.21	-4.06	0.26	1.52	0.25	-4.30	0.33
	24	5.52	0.27	-3.06	0.09	5.69	0.37	-3.24	0.19
	25	10.23	0.35	-2.56	0.15	10.60	0.45	-2.65	0.20
	26	10.29	0.34	-1.74	0.25	10.60	0.40	-1.70	0.24
	27	9.90	0.47	-0.28	0.10	9.87	0.28	-0.28	0.14
	28	9.95	0	-1.49	0	9.60	0.33	-1.72	0.21
	29	5.71	0	-.08	0	5.84	0.40	-0.18	0.18

(Continued)

APPENDIX X (CONTINUED)

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
IV	*27'					2.27	0.62	-10.28	0.54
	*28'					2.87	0.31	-10.22	0.54
	*29'					3.63	0.75	-9.88	0.59
V	30					-0.29	0.38	-10.76	0.55
	31					-2.37	0.26	-3.54	0.24
	32	0.15	0.05	0	0.01	0		0	
	33	0.69	0.16	-0.51	0.08	0.66	0.13	-0.56	0.07
	34	7.44	0.24	-4.73	0.35	8.38	0.40	-4.82	0.23
	35	8.73	0.29	-2.35	0.21	8.83	0.27	-2.29	0.28
	36	8.44	0.56	-2.26	0.16	8.44	0.33	-2.22	0.22
	37	8.83	0.22	-0.07	0.05	8.63	0.32	-0.09	0.09
	*37'					-2.36	0.16	-0.04	0.13
VI	38	-1.30	0.15	0.02	0.11	-1.13	0.16	0.01	0.11
	39	-0.30	0.14	0.01	0.01	0		0	
	40	-1.90	0.23	-1.50	0.23	-1.73	0.30	-1.72	0.16
	41	-1.04	0.09	-1.97	0.08	-0.83	0.29	-2.05	0.26
	42	3.43	0.38	-7.47	0.23	3.49	0.36	-7.40	0.22
	43	2.35	0.47	-9.79	0.42	1.76	0.68	-10.58	0.53
	44	3.79	0.28	-8.03	0.27	3.86	0.27	-8.18	0.30
	45	8.24	0.26	-5.64	0.26	8.46	0.32	-5.80	0.30
	46	8.09	0.29	-5.54	0.24	8.03	0.26	-5.50	0.22
	47	9.24	0.30	-3.08	0.22	9.31	0.33	-3.10	0.23
	48	9.07	0.32	-3.04	0.23	9.01	0.30	-3.05	0.24
	49	9.80	0.14	-0.25	0.07	9.28	0.36	-0.14	0.09
VII	50	-0.72	0.19	-3.26	0.36	-0.83	0.25	-3.08	0.38
	51	-1.13	0.43	-6.11	0.36	-1.28	0.41	-6.23	0.35
	52	3.46	0.31	-7.75	0.22	3.61	0.33	-7.84	0.21
	53	5.74	0.37	-7.84	0.08	5.76	0.33	-8.12	0.29
	54	9.34	0.42	-5.72	0.18	9.27	0.40	-5.64	0.21
	55	9.66	0.25	-5.84	0.11	9.69	0.48	-6.00	0.23
	56	10.30	0.28	-3.09	0.32	10.71	0.26	-3.06	0.31
	57	11.07	0.22	-3.30	0.25	11.04	0.30	-3.15	0.34
	58	10.99	0.20	-0.28	0.19	10.97	0.41	-0.22	0.19
	*58'					0		0	

* Prime numbered sites not included in linear analysis.

APPENDIX XI

OPERATED SIDE SHAM CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1(O)	-0.01	0	0.10	0	0		0	
	2	1.19	0.16	0.55	0.09	1.21	0.15	0.62	0.08
	3	3.82	0	2.11	0.20	4.19	0.35	2.69	0.23
	4	7.04	0.34	1.65	0.17	7.23	0.35	1.78	0.17
	5	7.58	0.33	0.14	0.08	7.76	0.35	0.14	0.09
	6(D)	7.41	0.31	0.14	0.08	7.40	0.31	0	
II	7(O)	0.02	0.04	0.14	0.07	0		0	
	8	0	0.11	1.36	0.15	-0.12	0.09	1.43	0.14
	9	6.61	0.26	2.61	0.14	7.75	0.39	2.95	0.16
	10	7.49	0.25	1.71	0.08	7.48	0.25	1.94	0.09
	11	7.83	0.33	1.77	0.07	8.27	0.38	1.84	0.10
	12	8.00	0.34	0.07	0.08	8.27	0.40	0.07	0.08
	13	7.61	0.35	0.09	0.04	7.60	0.34	0	
III	*14'					0.19	0.12	-1.74	0.18
	14(O)	0.31	0.04	0.14	0.04	0		0	
	15	0.42	0.14	1.65	0.16	0.29	0.15	1.73	0.17
	16	2.69	0.22	3.97	0.20	2.59	0.22	4.07	0.22
	17	4.32	0.31	5.23	0.37	5.17	0.47	6.56	0.33
	18					7.22	0.40	4.95	0.33
	19					10.53	0.45	1.50	0.19
	20					10.30	0.53	1.15	0.14
	21	9.84	0.12	0.57	0.08	10.65	0.51	0.61	0.10
	*21'(D)	9.69	0	0	0	10.38	0.58	0	
IV	*22'(O)					0		0	
	22	0.29	0.20	1.69	0.13	-0.22	0.17	1.69	0.12
	23	1.39	0.16	4.06	0.26	1.44	0.17	4.21	0.42
	24	6.39	0.22	2.77	0.20	6.02	0.43	2.92	0.36
	25	10.80	0.36	2.38	0.16	11.28	0.48	2.58	0.24
	26	11.02	0.40	1.51	0.18	11.36	0.51	1.55	0.20
	27(D)	10.65	0.53	0.09	0.09	10.49	0.45	0	
	28	9.98	0.12	1.38	0.10	10.17	0.30	1.49	0.15
	29	6.18	0.63	-0.07	0.09	6.19	0.58	-0.03	0.11
	*27'					2.46	0.37	10.25	0.51
	*28'					3.23	0.38	10.10	0.59
	*29'					4.07	0.44	9.77	0.57

(Continued)

APPENDIX XI (CONTINUED)

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
V	30					-0.50	0.37	10.93	0.64
	31					-2.89	0.54	3.64	0.40
	32(O)	0.20	0.14	0	0	0		0	
	33	1.06	0.18	0.62	0.12	1.06	0.45	0.70	0.20
	34	7.64	0.30	4.40	0.35	8.51	0.51	4.60	0.30
	35	8.72	0.44	2.03	0.23	8.82	0.41	1.98	0.29
	36	8.42	0.65	1.87	0.34	8.21	0.60	1.83	0.34
	37(D)	8.21	0	0	0	8.61	0.43	0	
	*37'					-2.85	0.17	0.19	0.18
VI	38	-1.24	0.16	-0.16	0.47	-1.11	0.20	-0.08	0.34
	39(O)					0		0	
	40	-1.70	0.14	1.72	0.10	-1.80	0.13	1.84	0.14
	41	-0.93	0.20	2.25	0.36	-0.76	0.17	2.29	0.35
	42	3.39	0.30	7.55	0.19	3.41	0.31	7.47	0.20
	43	2.27	0.41	10.10	0.29	1.66	0.45	10.79	0.34
	44	4.05	0.30	8.16	0.19	4.06	0.30	8.24	0.16
	45	8.63	0.32	5.33	0.35	8.83	0.31	5.44	0.44
	46	8.47	0.28	5.26	0.36	8.38	0.27	5.21	0.31
	47	9.60	0.24	2.72	0.14	9.68	0.26	2.71	0.14
	48	9.41	0.25	2.72	0.13	9.31	0.25	2.71	0.14
	49(D)	9.67	0.61	0.05	0.07	9.56	0.35	0	
VII	50	-0.66	0.34	3.70	0.49	-0.80	0.35	3.58	0.50
	51	-1.14	0.30	6.08	0.64	-1.24	0.30	6.18	0.69
	52	3.74	0.44	7.86	0.23	3.82	0.43	7.98	0.24
	53	6.23	0.44	7.70	0.25	6.26	0.41	7.97	0.29
	54	9.87	0.57	5.42	0.45	9.76	0.58	5.33	0.46
	55	10.01	0.68	5.35	0.41	10.22	0.64	5.66	0.42
	56	11.09	0.50	2.77	0.25	11.01	0.48	2.76	0.25
	57	11.22	0.55	2.81	0.27	11.27	0.51	2.83	0.27
	58(D)	12.50	0	0.20	0	11.32	0.56	0	0
	58'(O)					0		0	

O Point of origin.
D Point of X direction.
* Prime numbered sites not included in linear analysis.

APPENDIX XII

UNOPERATED SIDE SHAM CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE
STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1	0	0.01	-0.17	0.10	-0.01	0.06	-0.08	0.08
	2	1.14	0.15	-0.73	0.12	1.17	0.15	-0.75	0.13
	3	3.64	0.26	-2.17	0.15	4.23	0.48	-2.91	0.26
	4	7.03	0.39	-1.87	0.16	7.22	0.41	-2.02	0.16
	5	7.62	0.31	-0.33	0.10	7.79	0.36	-0.32	0.08
	6	7.41	0.33	-0.31	0.06	7.41	0.31	-0.18	0.10
II	7	0.03	0.07	-0.23	0.08	0.03	0.08	-0.10	0.07
	8	0.04	0.10	-1.46	0.11	-0.11	0.10	-1.51	0.11
	9	6.61	0.36	-2.78	0.24	7.79	0.55	-3.01	0.22
	10	7.46	0.36	-1.80	0.13	7.45	0.36	-2.02	0.17
	11	7.88	0.42	-1.84	0.13	8.30	0.49	-1.88	0.14
	12	8.03	0.35	-0.14	0.09	8.27	0.42	-0.13	0.11
	13	7.62	0.32	-0.17	0.07	7.62	0.32	-0.08	0.07
III	*14'					0.23	0.11	-2.06	0.25
	14	0.99	0.20	-3.79	0.42	0.61	0.14	-3.73	0.37
	15	1.72	0.31	-5.29	0.49	1.61	0.31	-5.39	0.53
	16	4.59	0.29	-6.67	0.55	4.48	0.30	-6.83	0.53
	17	6.37	0.24	-7.49	0.54	7.63	0.34	-8.40	0.71
	18					9.23	0.58	-5.93	0.54
	19	10.08	0	-1.65	0	11.07	0.53	-1.69	0.15
	20					10.78	0.62	-1.41	0.19
	21	10.07	0.07	-0.73	0.13	10.88	0.55	-0.70	0.14
	*21'	9.69		0		10.39	0.62	-0.07	0.05
IV	*22'					-0.01	0.03	-0.23	0.19
	22	0.25	0.23	-1.89	0.40	-0.30	0.21	-1.92	0.37
	23	1.21	0.25	-4.34	0.29	1.29	0.23	-4.46	0.29
	24	6.18	0.48	-2.86	0.21	6.13	0.35	-3.29	0.46
	25	10.92	0.41	-2.59	0.07	11.42	0.55	-2.79	0.36
	26	11.05	0.42	-1.56	0.23	11.44	0.50	-1.58	0.25
	27	10.66	0.53	-0.34	0.08	10.47	0.47	-0.23	0.10
	28	9.94	0.21	-1.55	0.14	10.17	0.33	-1.62	0.20
	29	6.18	0.64	-0.10	0.11	6.19	0.56	-0.09	0.10
	*27'					2.15	0.50	-10.59	0.83
	*28'					2.73	0.70	-10.50	0.84
	*29'					3.70	0.66	-10.16	0.87

(Continued)

APPENDIX XII (CONTINUED)

Region	Site	ORIGINAL X	SD	Y	SD	FINAL X	SD	Y	SD
V	30					-0.84	0.35	-10.94	0.85
	31					-2.95	0.51	-3.51	0.33
	32	0.20	0.14	-0.01	0	0		0	
	33	1.07	0.27	-0.50	0.16	1.07	0.42	-0.58	0.18
	34	7.35	0.29	-4.68	0.39	8.25	0.56	-4.91	0.46
	35	8.61	0.42	-2.31	0.42	8.70	0.43	-2.33	0.42
	36	8.37	0.67	-2.23	0.45	8.09	0.64	-2.21	0.39
	37	8.50	0.35	-0.31	0.10	8.60	0.43	-0.07	0.20
	*37'					-2.86	0.19	0.07	0.21
VI	38	-1.24	0.17	-0.14	0.47	-1.11	0.20	-0.08	0.34
	39					0		0	
	40	-1.66	0.13	-1.75	0.09	-1.79	0.20	-1.88	0.14
	41	-0.88	0.15	-2.38	0.26	-0.68	0.22	-2.29	0.31
	42	3.45	0.32	-7.61	0.22	3.53	0.27	-7.55	0.21
	43	2.48	0.49	-10.00	0.30	1.89	0.45	-10.69	0.34
	44	4.02	0.39	-8.29	0.22	4.04	0.43	-8.34	0.24
	45	8.44	0.45	-5.52	0.25	8.74	0.40	-5.66	0.32
	46	8.37	0.37	-5.43	0.24	8.31	0.35	-5.39	0.23
	47	9.53	0.32	-3.05	0.16	9.59	0.35	-3.05	0.16
	48	9.33	0.33	-3.03	0.17	9.23	0.33	-3.02	0.17
	49	9.54	0.50	-0.37	0.12	9.56	0.50	-0.32	0.14
VII	50	-0.51	0.24	-3.63	0.47	-0.66	0.23	-3.47	0.45
	51	-0.08	0.36	-6.14	0.52	-1.12	0.37	-6.27	0.56
	52	3.79	0.56	-7.93	0.20	3.94	0.58	-8.09	0.21
	53	6.22	0.48	-7.56	0.36	6.29	0.44	-7.91	0.27
	54	9.87	0.55	-5.42	0.38	9.75	0.53	-5.32	0.38
	55	10.23	0.48	-5.47	0.23	10.28	0.57	-5.71	0.34
	56	11.11	0.51	-3.03	0.33	11.01	0.51	-3.00	0.34
	57	11.32	0.53	-3.11	0.37	11.39	0.54	-2.09	0.36
	58	11.72	0.96	-0.75	0.35	11.32	0.53	-0.20	0.12
	58'					0		0	

* Prime numbered sites not included in linear analysis.

APPENDIX XIII

OPERATED SIDE EXTRACTION CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1(O)	0	0.01	0.07	0.07	0		0	
	2	1.39	0.23	0.64	0.07	1.40	0.20	0.72	0.07
	3	4.95	0.35	2.59	0.18	4.94	0.34	3.02	0.18
	4	7.81	0.27	1.74	0.14	8.02	0.29	1.94	0.19
	5	8.32	0.24	0.16	0.08	8.43	0.23	0.15	0.07
	6(D)	8.05	0.22	0.17	0.05	8.04	0.22	0	
II	7(O)	0	0.01	0.13	0.05	0		0	
	8	0.03	0.11	1.56	0.19	-0.09	0.13	1.64	0.18
	9	7.16	0.38	2.94	0.31	7.98	0.38	3.11	0.11
	10	7.93	0.25	1.83	0.06	7.94	0.24	2.04	0.05
	11	8.27	0.32	1.84	0.07	8.59	0.32	1.86	0.09
	12	8.32	0.34	0.08	0.05	8.58	0.35	0.07	0.05
	13(D)	7.92	0.27	0.10	0	7.92	0.27	0	
III	*14'					0.20	0.13	-1.78	0.14
	14(O)	0.27	0.05	0.14	0.06	0		0	
	15	0.47	0.11	1.98	0.31	0.42	0.15	1.92	0.18
	16	2.86	0.17	4.31	0.17	2.88	0.22	4.39	0.24
	17	4.46	0.27	5.97	0.27	5.23	0.35	6.97	0.25
	18					7.56	0.34	5.26	0.48
	19	10.58	0	1.70	0	11.03	0.17	1.60	0.18
	20	10.65	0	1.01	0	10.73	0.13	1.10	0.36
	21	10.88	0	0.73	0	11.08	0.14	0.63	0.15
	*21'(D)					10.76	0.20	0	
IV	*22'(O)					0		0	
	22	1.42	0	1.79	0	0.35	0.38	1.78	0.22
	23	1.82	0.15	4.02	0.12	2.04	0.25	4.21	0.31
	24	6.35	0.68	2.68	0.42	6.42	0.39	3.13	0.28
	25	11.35	0.20	2.35	0.27	11.74	0.19	2.44	0.28
	26	11.40	0.16	1.29	0.26	11.66	0.19	1.26	0.28
	27(D)	10.81	0.19	0.01	0.09	10.73	0.18	0	
	28	10.48	0.11	1.19	0.17	10.56	0.16	1.28	0.32
	29	6.67	0.24	-0.14	0.15	6.67	0.24	-0.14	0.15

(Continued)

APPENDIX XIII (CONTINUED)

Region	Site	ORIGINAL X	SD	Y	SD	FINAL X	SD	Y	SD
IV	*27'					2.71	0.48	10.95	0.20
	*28'					3.46	0.49	10.61	0.42
	*29'					4.23	0.57	10.39	0.29
V	30	-0.66	0.58	11.38	0.32	-0.12	0.54	11.75	0.35
	31					-2.95	0.17	3.38	0.27
	32(O)	0.25	0.10	-0.01	0.03	0		0	
	33	0.79	0.29	0.51	0.14	0.83	0.32	0.56	0.13
	34	8.27	0.46	4.74	0.28	8.89	0.23	4.83	0.14
	35	9.21	0.26	2.16	0.32	9.31	0.23	2.18	0.32
	36	8.86	0.44	2.11	0.37	8.66	0.41	2.05	0.39
	37(D)	8.95	0.36	0		9.13	0.23	0	
	*37'					-2.80	0.15	-0.07	0.16
VI	38	-1.35	0.14	0.03	0.11	-1.22	0.15	-0.10	0.34
	39(O)	-0.26	0.06	0	0.05	0		0	
	40	-1.75	0.17	1.89	0.11	-1.94	0.19	1.98	0.23
	41	-1.01	0.18	2.61	0.30	-0.71	0.30	2.62	0.25
	42	3.77	0.50	7.74	0.11	3.65	0.48	7.67	0.14
	43	2.70	0.69	10.58	0.41	2.53	0.76	10.95	0.38
	44	4.29	0.46	8.48	0.17	4.34	0.45	8.54	0.14
	45	8.95	0.51	5.58	0.30	9.16	0.50	5.67	0.31
	46	8.76	0.51	5.44	0.29	8.67	0.51	5.39	0.27
	47	9.93	0.49	2.82	0.30	10.02	0.48	2.82	0.30
	48	9.70	0.51	2.80	0.28	9.60	0.51	2.79	0.26
	49(D)	9.98	0.34	0.13	0.05	9.82	0.47	0	
VII	50	-0.56	0	3.49	0	-0.66	0	3.39	0
	51	-1.41	0	6.18	0	-1.41	0	6.28	0
	52	3.75	0	8.47	0	3.75	0	8.57	0
	53	6.99	0.54	7.55	0.36	7.10	0.60	8.83	0.28
	54	10.48	0.31	4.93	0.49	10.36	0.31	4.87	0.47
	55	10.78	0.40	5.11	0.45	11.09	0.43	5.27	0.45
	56	11.60	0.34	2.55	0.34	11.52	0.32	2.55	0.33
	57	11.93	0.34	2.63	0.36	12.10	0.34	2.63	0.36
	58(D)					11.93	0.37	0	
	*58'(O)	0.26	0.10	-0.01	0.04	0		0	

O Point of origin.
D Point of X direction.
* Prime numbered sites not included in linear analysis.

APPENDIX XIV

UNOPERATED SIDE EXTRACTION CRANIUM

MEANS AND STANDARD DEVIATIONS OF THE STANDARDIZED COORDINATES IN MILLIMETERS

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
I	1	0	0.02	-0.14	0.10	0	0.01	-0.07	0.07
	2	1.32	0.23	-0.74	0.07	1.39	0.20	-0.82	0.07
	3	4.81	0.42	-2.79	0.12	4.87	0.38	-3.18	0.25
	4	7.77	0.30	-1.92	0.12	7.93	0.30	-2.11	0.18
	5	8.31	0.23	-0.34	0.07	8.45	0.23	-0.34	0.07
	6	8.04	0.20	-0.37	0.08	8.04	0.20	-0.21	0.05
II	7	0.04	0.09	-0.21	0.06	0.05	0.08	-0.07	0.05
	8	0.03	0.12	-1.67	0.21	-0.12	0.12	-1.74	0.21
	9	7.12	0.46	-3.04	0.26	7.94	0.49	-3.28	0.26
	10	7.92	0.28	-1.98	0.21	7.91	0.28	-2.15	0.21
	11	8.21	0.34	-2.01	0.22	8.55	0.36	-2.01	0.21
	12	8.32	0.32	-0.22	0.03	8.58	0.33	-0.20	0.04
	13	7.97	0.30	-0.18	0.04	7.97	0.30	-0.10	0.05
III	*14'					0.25	0.15	-2.15	0.20
	14	0.99	0.12	-4.03	0.19	0.65	0.08	-4.02	0.21
	15	1.67	0.19	-5.51	0.34	1.57	0.20	-5.63	0.34
	16	4.81	0.28	-7.05	0.34	4.77	0.25	-7.09	0.34
	17	6.96	0.25	-7.98	0.35	8.02	0.31	-8.67	0.43
	18					9.66	0.40	-6.12	0.37
	19	11.23	0	-1.65	0	11.69	0.17	-1.62	0.12
	20	11.06	0	-0.96	0	11.29	0.14	-1.30	0.11
	21	11.12	0	-0.56	0	11.38	0.15	-0.66	0.13
	*21'					10.77	0.20	-0.11	0.10
IV	*22'					-0.04	0.06	-0.25	0.08
	22	0.13	0.17	-2.18	0.06	-0.35	0.14	-2.18	0.05
	23	1.07	0.21	-4.66	0.10	1.07	0.22	-4.79	0.30
	24	6.62	0.29	-3.28	0.14	6.43	0.36	-3.52	0.14
	25	11.40	0.20	-2.79	0.12	11.75	0.23	-2.87	0.14
	26	11.50	0.18	-1.59	0.28	11.74	0.17	-1.58	0.28
	27	10.89	0.21	-0.42	0.20	10.74	0.16	-0.30	0.23
	28	10.47	0.16	-1.44	0.31	10.59	0.18	-1.66	0.32
	29	6.67	0.24	-0.16	0.17	6.67	0.24	-0.16	0.17

(Continued)

APPENDIX IV (CONTINUED)

Region	Site	ORIGINAL				FINAL			
		X	SD	Y	SD	X	SD	Y	SD
IV	27'					2.36	0.37	-11.26	0.24
	28'					3.13	0.49	-11.11	0.27
	29'					3.95	0.67	-10.79	0.31
V	30					0.07	0.64	-11.80	0.04
	31					-3.29	0.16	-3.44	0.28
	32	0.25	0.10	-0.01	0.03	0		0	
	33	0.94	0.22	-0.44	0.04	0.78	0.29	-0.65	0.19
	34	8.04	0.21	-4.92	0.28	8.81	0.23	-5.09	0.20
	35	9.12	0.26	-2.41	0.32	9.19	0.25	-2.42	0.34
	36	8.73	0.40	-2.30	0.38	8.57	0.37	-2.24	0.37
	37	8.90	0.42	-0.25	0.07	9.09	0.27	-0.20	0.11
	*37'					-2.86	0.16	-0.16	0.27
VI	38	-1.35	0.14	0.03	0.11	-1.22	0.15	-0.10	0.34
	39	-0.26	0.06	0	0.05	0		0	
	40	-1.82	0.10	-1.81	0.15	-1.94	0.17	-1.94	0.20
	41	-0.86	0.27	-2.45	0.32	-0.68	0.29	-2.46	0.29
	42	3.75	0.38	-7.69	0.27	3.78	0.40	-7.64	0.28
	43	2.53	0.54	-10.75	0.28	2.35	0.62	-11.16	0.32
	44	4.20	0.45	-8.42	0.39	4.26	0.44	-8.47	0.33
	45	8.98	0.39	-5.44	0.33	9.17	0.36	-5.50	0.34
	46	8.77	0.39	-5.34	0.32	8.68	0.39	-5.27	0.32
	47	9.89	0.44	-2.67	0.26	9.97	0.43	-2.67	0.26
	48	9.67	0.42	-2.65	0.27	9.47	0.52	-2.63	0.28
	49	9.93	0.38	-0.25	0.13	9.79	0.58	-0.19	0.14
VII	50	-0.43	0	-3.81	0	-0.54	0	-3.71	0
	51	-1.09	0	-6.52	0	-1.19	0	-6.62	0
	52	3.95	0	-8.53	0	4.05	0	-8.63	0
	53	6.53	0.49	-7.77	0.18	6.54	0.45	-8.13	0.22
	54	10.13	0.66	-5.40	0.25	10.05	0.62	-5.32	0.23
	55	10.44	0.57	-5.64	0.33	10.68	0.44	-5.78	0.44
	56	11.43	0.53	-3.29	0.58	11.35	0.50	-3.26	0.56
	57	11.71	0.45	-3.19	0.46	11.82	0.44	-3.35	0.60
	58	12.01	0.36	-0.43	0.21	11.79	0.35	-0.58	0.76
	*58'	0.26	0.10	-0.01	0.04	0		0	

* Prime numbered sites not included in linear analysis.