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A Roengenographic Study of the Trabecular Pattern of the Alveolar Processes of the Human Maxilla and Mandible

Nicholas Joseph Brescia
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A Roentgenographic Study
Of The Trabecular Pattern Of The Alveolar Processes
Of The Human Maxilla And Mandible

by

Nicholas Joseph Brescia, D.D.S.

A Thesis Submitted to the Faculty of the Graduate
School of Loyola University in Partial
Fulfillment of the Requirements
for the Degree of
Master of Science
June
1959
LIFE

Nicholas J. Brescia was born May 10, 1923 in Chicago, Illinois.

He was graduated from the J. Sterling Morton High School, Cicero, Illinois as valedictorian of his class in February 1941. From 1941 to 1943 he attended the University of Illinois, Loyola University, and the University of Notre Dame for his undergraduate studies. World War II intervened and after two and a half years of Naval Hospital duty he returned to Loyola University to complete his undergraduate course.

In September 1946 he began studies at Loyola University School of Dentistry and received the Doctor of Dental Surgery Degree in June 1950. He was then appointed to the faculty of Loyola Dental School and in 1953 he was advanced to assistant professor of anatomy and histology. In 1955 he was appointed as a consultant to the Council on Dental Education of the American Dental Association. He is presently Chairman of Admissions to the Dental School and is currently writing a textbook of dental anatomy for the C.V. Mosby Co. His graduate studies began in the Department of Oral Anatomy of Loyola University in September 1957.
ACKNOWLEDGEMENT

To Doctor Harry Sicher, under whose suggestion this problem was undertaken, I wish to acknowledge his constant advice and supervision. His constant tutoring has enabled me to appreciate the fact that a good teacher must at the same time be a researcher.

The author wishes also to thank Doctor Frank M. Wentz and Doctor Edward M. Nelson for valuable assistance and criticism.
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CHAPTER I

INTRODUCTION

A short review of the gross anatomy of the maxilla and mandible, the bones of the masticatory apparatus, is necessary to evaluate the findings of this investigation.

The maxilla or upper jaw is fixed to the base of the neurocranium and has an architecture differing from the mandible or lower jaw. Grossly one immediately recognizes its fragile appearance. This is due to thinner cortical plates of bone and also to the maxillary sinuses hollowing out the body of the maxilla in its lateral aspects. The intervention of the nasal aperture further adds to its seemingly delicate nature. From a teleological viewpoint we can recognize nature's law of economy.

This delicate structure of the maxilla is of course compensated by the buttressing effect of the canine pillars, zygomatic pillars, and pterygoid pillars. These vertical reinforced bony pillars with horizontal heavy ridges of bone such as the supraorbital and infraorbital ridges connecting them, counteract the heavy masticatory force placed on the maxillary dentition.

The mandible, the movable bone of the masticatory unit, presents a much different morphologic picture. The mandible is composed of heavy cortical plates of bone giving it a massive
appearance. Its suspension by the pull of strong musculature is evident in the heavily reinforced borders extending from the posterior angle of the mandible to the mental region. The ramus has two bony processes, the coronoid and the condylar. Sicher and Weinmann (1947): "The mandible resists bending forces with its strong compact layer. The compact shell is filled with cancellous bone forming and surrounding the sockets of the teeth. The alveolar process is defined as that area of the maxilla and mandible occupied by the dentition. The roots of the teeth are contained in their bony sockets suspended by ligaments from the alveolar bone proper. The masticatory pressure exerted upon the teeth is transmitted as traction to the alveolar bone proper (lamina dura) via the principal fibers of the periodontal membrane. The alveolar bone proper tends to sink into the bone if the tooth is under pressure: this tendency is counteracted by the spongy bone around the alveolar bone proper. These trabeculae arise on the outer surface of the lamina dura. Some are horizontal and connect the sockets of two adjacent teeth; others are arranged in an approximately cone-shaped field and end in part on the compact alveolar plates or on the lamina dura of adjacent teeth. Because of their specific function, the spongy trabeculae and the compact alveolar plates are designated as supporting bone of the alveolar process.
Some of the spongy trabeculae surrounding the apical part of the sockets unite as a trajectory which runs backward below the sockets and then diagonally upward and backward through the ramus to end in the condyle. In this way the masticatory pressure is finally transmitted to the base of the skull via temporomandibular articulation. This most important trajectory of the mandible, the dental trajectory, bulges on the inner surface of the ramus as a blunt crest or ridge of the mandibular neck.

Other trajectories of the mandible are formed in response to the forces exerted by the muscles of mastication. One is found in the region of the mandibular angle; another starts at the tip of the coronoid process, fanning out into the mandibular body. Between these trajectories there is a region of the mandible, above and in front of the angle, where the cancellous bone is relatively free of stresses. In this region the trabeculae of the spongy bone are thin and the marrow spaces wide, a fact which can also be verified from the observation of roentgenograms.

The region of the chin is especially endangered if bending forces act upon the mandibular body. Forceful forward thrust of the mandible causes a measurable deformation; namely, a contraction of the mandible by the inward pulling component of the two external pterygoid muscles. In response to these forces the region of the chin is strengthened not only by the rather massive
compacts of the mental protuberance, but also by trajectories of the spongiosa. These tracts of trabeculae cross each other at right angles, running from the right lower border of the chin upward to the left into the alveolar process and vice-versa."

It is in the area of the supporting spongy bone of the alveolar processes of maxilla and mandible that the attempt to classify trabecular patterns will be made. It would be well to outline the radiographic translucent and radiopaque anatomical landmarks to avoid confusion in roentgenographic interpretation. Since negative films are clinically used, the following description is taken from the appearance of the details on the negative film.

RADIOLUCENT LANDMARKS OF THE MAXILLA
McGall and Wald (1957)
Epstein (1953)

A. Antrum or Maxillary Sinus:

The antrum or maxillary sinus appears as a dark or radiolucent area above the upper molars extending as far forward as the premolars and in extreme cases to the canine area. The wall of the sinus appears as a white irregular line along its periphery.

B. Nasal cavity:

The nasal cavity appears as a dark area above the upper incisor teeth. The light line bisecting the area if the x-ray
is directed in the sagittal plane is the nasal septum.

C. Incisive foramen:
The incisive foramen appears as a dark area above and between the upper central incisors.

D. Median palatine suture:
The median palatine suture appears as a thin irregular dark line starting between the central incisors and running posteriorly in almost a straight line through the palate.

E. Posterior palatine foramen:
The posterior palatine foramen appears as a dark area on the palate usually above the lingual root of the upper first molars.

RADIOLUCENT LANDMARKS OF THE MANDIBLE

A. Mental foramen:
The mental foramen is a dark oval area situated below and between the premolars. In some instances it is directly below the second premolar.

B. Mandibular canal:
The mandibular canal is a broad dark line extending from the mandibular foramen through the body of the mandible, in close approximation to the roots of the third molar and then assuming a position towards the inferior one third of the body of the mandible.
C. Interdental or nutrient canals:

The interdental or nutrient canals appear as dark lines running vertically in the anterior region of the mandible through the interdental septa.

RADIOPAQUE LANDMARKS OF THE MAXILLA

A. Mandibular Coronoid process:

The mandibular coronoid process on intraoral roentgenograms is seen as a triangular gray area superimposed in the upper molar region of the maxilla.

B. Hamular process or pterygoid process of the sphenoid bone:

The hamular process or pterygoid process of the sphenoid bone appears as a hook shaped distal to the tuberosity of the maxilla. It resembles a bluntly pointed fish hook.

C. Maxillary tuberosity:

The maxillary tuberosity is an upward and distal convex curvature of the maxilla distal to the third molar.

D. Body of the zygomatic bone:

The body of the zygomatic bone is seen as a dense white area above the molars—especially the first and second molars, sometimes obscuring the roots.
RADIOPAQUE LANDMARKS OF THE MANDIBLE

A. Genial tubercules:

The genial tubercules appear as a white ring with a dark center beneath the lower central incisors.

B. Outline of mental protuberance:

The outline of mental protuberance appears as a dense white line extending from the symphysis to the premolar region.
CHAPTER II
REVIEW OF THE LITERATURE

The classification elaborated by Simpson in 1947 is as follows:

1. There is alveolar bone with abundant uniform cancellations and exceptionally small medullary spaces.
2. There is alveolar bone with irregular and sharply defined cancellations which produce confusing radiopaque whorls.
3. There is alveolar bone of a fantastic design and various trabecular combinations. The cancellations are uniform around the second bicuspid but there are traces of interdental canals throughout the region and either a canal or a chain of communicating medullary spaces between the roots of the first molar, this pattern is not unusual in the mandibular first molar region and should be recognized as a structural peculiarity.
4. There is alveolar bone in which the trabeculae are widely separated and are almost entirely horizontal. The large radiolucent medullary spaces are perplexing.
5. There is dense alveolar bone with radiopaque areas radiating lines.
6. There is uniformly dense alveolar bone in which there is no contrasting image of the lamina dura and only in some areas are the medullary spaces faintly visible.

7. There is contrasting alveolar bone in which all the cancellations are around the roots of the teeth and the remainder of this mandibular section being a medullary canal similar to that of more typically long bones."

Gerson (1955-56) states that normally the trabeculae are regularly distributed, and usually uniform in length and thickness, with the larger trabeculae paralleling the lines of maximum stress. The marrow spaces are also regularly distributed.

Updegrave (1958) states that the cancellous portion of the mandible presents an entirely different trabecular pattern than that of the maxilla. He describes the cancellous portions of the maxilla as a uniform pattern of small even spaced trabeculations with the intertrabecular spaces becoming larger in the region of the tuberosities. He further states that the cancellous bone pattern in the anterior region of the mandible shows a more regular horizontal arrangement of the trabeculae with the marrow spaces fairly uniform from the apices of the teeth to the lower border of the jaw. The anterior trabecular pattern of the mandible is coarser than the corresponding region in the maxilla. He agrees with Simpson about a pattern of wide marrow spaces around
the first molar. Updegrave found that loss of teeth and age cause pattern change.

Goldman and Brenman (1957) found that removal of buccal and lingual alveolar plates of bone had no effect on the trabecular pattern around the teeth as shown on the radiograph, but that only the density of the radiograph was affected.

Becks (1948) studied five lower jaws roentgenographically and then examined them histologically. In all cases the histologic study compared with the roentgenographs made previously. Becks elaborated as follows: "When standard radiographic technique is used any differences in the shade of image are due to differences in density of ossification and combined thickness of cortical plates. The number of bone trabeculae between the cortical plates and alveolar bone is not only dependent on the functional requirements which the jaw bone has to meet, but also on general systemic conditions which effect bone metabolism and control the laws of bone resorption and apposition. The jaw structures are not stable and as the trabeculae are a storehouse of important minerals which the body may make demand on in time of need, it must be emphasized that morphologic changes may occur anytime. They do so in a characteristic manner and knowledge of these changes from the standpoint of radiographic interpretation becomes an extremely important asset in dental practice."
Ritchey and Orban (1953) examined the outline of the crest of the interdental septa and came to the following conclusions:

"The outlines of the crest of the alveolar septa, as they appear in the roentgenogram, are dependent upon the position of the adjacent teeth. In a healthy mouth the distance between the cemento-enamel junction and the free border of the alveolar bone proper is fairly constant. In consequence the alveolar crest is often oblique if the neighboring teeth are inclined. In the majority of individuals the inclination is most pronounced in the premolar and molar region, the teeth being tipped mesially. Then the cemento-enamel junction of the mesial teeth is situated in a more occlusal plane than that of the distal tooth, and the alveolar crest therefore slopes distally."

A summary of the classifications of the trabecular patterns as found in the literature up to date is as follows: Simpson (1947) saw and recognized regular and irregular patterns, however, his attempt of typing failed because his classification rested on insignificant differences. Consequently his classification was long and complicated.

Gerson (1955-56) classified only one type of trabecular pattern and the explanation of this general pattern is ambiguous and inconsistent with the findings of other authors.
Updegrave (1958) emphasized the existence of pattern differences upon comparison of the maxilla and mandible, and further stated that there were pattern differences between adjacent areas of the alveolar processes of the same jaw. All authors are in accord with the existence of relatively larger marrow spaces around the roots of mandibular first molar teeth.
CHAPTER III
MATERIAL AND METHODS

The need for a simple and exact classification of trabecular patterns is great. We know from the literature (Updegrave-1958) that the loss of one or more teeth brings about a disharmony in trabecular pattern; in addition older age groups exhibit a continued loss of trabeculae. Hence it seemed that the most logical choice of human subjects would be those with complete dentition; of the same sex (male); in a closed age group (20-30 years of age); and having no malocclusions. We assumed that the living subjects were in good health since all subjects were examined by the university medical department.

A complete roentgen exposure of the maxilla and mandible was made on sixty-four male patients whose average age is twenty-three years. The x-ray tube was directed at right angles to the following areas of the interdental and interradicular areas of the alveolar processes: incisor area, cuspid area, premolar area, and molar area. Fourteen exposures of the maxilla and mandible comprise an intraoral roentgenogram. The intraoral films were held in place with metal and rubber film holders: this is the parallel film placement technique used to prevent any image distortion on the negative.
As a comparison roentgen exposures were also made of twenty dry skull specimens of varying ages and sex. The right angle technique was used also. The purpose of comparing the living patients, all male, in a closed age group with the dry specimens of a wide range of age and mixed sex was to determine any similarity or difference between the two groups.

All roentgen exposures were made with the dental x-ray machine set at 20 milliamperage and 60 kvp. A total of eighty-four complete roentgenograms (full mouth x-rays) were taken. The dental x-ray machine had an 18" cone 2 mm. of aluminum filter, and a lead diaphragm. An intermediate speed film was used to establish greater detail on the negatives and was of recent manufacture.

Exposure times:

Maxillary teeth
Central incisors - 3 sec.
Lateral incisors and canines - 3.5 sec.
Premolars - 3.5 sec.
Molars - 4.0 sec.

Mandibular teeth
Central incisors - 2 sec.
Lateral incisors and canines - 2 sec.
Premolars - 2.5 sec.
Molars - 3.0 sec.
After exposure, the film used on the living patients was developed under controlled conditions: 5 minutes at 70°F; washed for 45 seconds; fixed for 15 minutes; washed for 20 minutes, and then hanged for drying. The same procedure was followed for the dry skull specimens except for developing time, 4 minutes at 70°F. After the films were washed and dried, they were mounted in a celluloid film holder.

All of the radiographs were studied by visual examination with an illuminated viewer as a background under magnification, using a 2 power lens. Special emphasis was placed on the following areas in the examinations; the alveolar bone proper (lamina dura); alveolar crest; the interalveolar or interdental septum, and the intraalveolar or interradicular septum of bone.

The arrangement and relative number of trabeculae were duplicated by semidiagrammatic drawings of the two main types of trabeculation and of extreme variants of each. These drawings will be included in the summary and conclusions as an auxiliary aid in pattern type identification. Since no previous standardization of the radiograph interpretation and classification was available in the literature it was necessary to develop a method. This investigation did not include a histologic study, hence no attempt was made to evaluate exactly the size of trabeculae.
Furthermore the determination of the size of marrow spaces is difficult because of the great number that exist in the alveolar processes of the maxilla and mandible. It was concluded that a pattern could only be determined by the position of the trabeculae and their relative number. All of the eighty-four roentgenograms were evaluated weekly for a period of eight weeks. There was a negligible percentage of error in these evaluations. The errors involved were almost exclusively the division into subtypes or the diagnosis of subtypes.

An additional examination was done as follows: five individuals were given a random selection of twenty complete roentgenograms after a half-hour of briefing on trabecular patterns of the alveolar processes. Their examination consisted in diagnosing pattern types and subtypes as described in this investigation from a study of the complete roentgenograms. This was a test designed to eliminate any subjectivity on the part of the investigator and to give proof of the findings. The results of this examination are found in the findings.
CHAPTER IV
FINDINGS

Examination of the radiographs revealed the following findings. There are two basic types of trabecular patterns in the alveolar processes of the maxilla and mandible. Furthermore, each of the two basic types can be divided into two subtypes. The basic pattern of the maxilla and mandible in each individual was found to be the same. The findings were derived from a detailed examination of specific areas of the alveolar processes.

The patterns were determined by analysis of the relation of the trabeculae to each other; relation of trabeculae to surrounding anatomical structures, and the number of trabeculae. The four subtypes are as follows: type I is a pattern of interdental and interradicular trabeculae regular and horizontal in arrangement. Type I can be divided into two subtypes: in subtype I A the trabeculae are relatively few and run at a greater distance from each other. In type I B the trabeculae are more numerous and not as widely spaced.

Type II shows a pattern of numerous and delicate interdental and interradicular trabeculae irregular in arrangement: type II can be divided into two subtypes: subtype II A. The number of trabeculae is relatively less than is found in subtype II B.
In all four types there was evident a tendency towards more trabeculae in the maxillary alveolar process as compared to the mandibular process in the same individual. A detailed description follows:

**Type I** Interdental and interradicular trabeculae regular and horizontal in arrangement.

**Subtype IA** (Trabeculae relatively few. Refer Fig. I and II)

The trabeculae are relatively few in number in the interdental and interradicular areas of the bone. The trabeculae have basically a horizontal position. In the interdental and interradicular areas the trabeculae are arranged in step-ladder like fashion extending from tooth to adjacent tooth like struts; in the interradicular area specifically from root to root of the same tooth. This arrangement is found in both maxilla and mandible. A little below the apices of the roots of the tooth the trabeculae decrease further in number giving an appearance of large radiolucent areas. Surrounding the apices of the roots of the mandibular first molars and second premolars there are very few trabeculae giving the appearance of large marrow spaces. The summit of the alveolar crest in the interdental septa is flattened in the area of the posterior tooth and is correlated to the cemento-enamel junction. The alveolar tubercle of the maxilla has fewer trabeculae and they are irregular in arrangement.
**Subtype I B** (Relatively more trabeculae. Refer Fig. III and IV).

In comparison to subtype I A the trabeculae are more numerous and basically compares with all other points outlined in the description of subtype I A.

**Type II** Interdental and interradicular trabeculae irregular in arrangement and numerous.

**Subtype II A** (Relatively fewer trabeculae. Refer Fig. V and VI).

The trabeculae are relatively fewer in number than subtype II B and are positioned obliquely and irregular. Alveolar crest findings; the typical large marrow spaces around the mandibular first molars and second premolars; the alveolar tubercle area all correspond to the evidence in subtypes I A and I B.

**Subtype II B** (Numerous trabeculae. Refer Fig. VII and VIII).

This subtype gives the appearance of a delicate lace like pattern of the trabeculae. The trabeculae are irregular in arrangement and relatively more numerous than in subtype II A. In all other subtypes the number of trabeculae in the mandible became less below the apices of the roots of the teeth; however, in subtype II B this lace like pattern extended below the roots of the teeth. Subtype II B compares with all other findings in subtype II A.
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| " 3             | (95%) | (87.5%) |
| " 4             | (95%) | (82.5%) |
| Investigator 5   | (100%) | (97.5%) |

% of Accuracy % of Accuracy

**N.B.** Examination Material--20 Roentgenograms
CHAPTER V
DISCUSSION

To avoid confusion in interpretation and diagnosis a classification of normal trabecular patterns of the alveolar processes of the maxilla and mandible is necessary. Simpson (1947) saw and recognized regular and irregular patterns; his attempt of typing failed because his classification rested on insignificant differences and because he did not recognize the importance of the arrangement of the trabeculae and their number. Updegrave (1958) emphasized pattern differences between the maxilla and mandible of the same individual. In addition he described pattern differences in adjacent areas of the same jaw. The findings of large marrow spaces around the roots of mandibular first molars were confirmed in this study but a further addition to this is the typically large marrow spaces extending to the mandibular second premolar. The large marrow spaces around the mandibular first molars and second premolars were found in all pattern types of this investigation.

The architecture of spongiosa structures has been studied in many bones of the skeleton and it has been found that stronger trabeculae are arranged in the lines of force and stress. These lines are known as trajectories. Hence, one speaks of trajectorial lines of the spongiosa. Applying this knowledge to the alveolar
processes of the maxilla and mandible the regular arrangement of the spongy trabeculae would have been expected. These trabeculae were supposed to buttress in their horizontal course one socket against the other.

Surprisingly enough in the examined group of sixty-four adult males this regular ladder-rung arrangement of trabeculae was found in 24/38% of the subjects. The majority of the examined individuals (40/62%) showed an irregular pattern of trabeculation. A functional trajectorial arrangement of the trabeculae was replaced by an irregular three dimensional network of trabeculae. In this type II, however, the number of trabeculae in any given area is considerably larger than in the corresponding area of the type I. It may be permissible to state that the lack of regular trabeculation probably was compensated by the greater number of trabeculae. Irregularity, however, is restricted to the alveolar processes. The regular arrangement of the "trajectories" of the mandible and the pillars of the maxilla is not influenced.

Marrow spaces regardless of pattern type tend to be slightly smaller in the maxilla than in the mandible. No pattern differences were noted upon comparison of anterior and posterior areas of the alveolar processes of each of the jaws in the same individual.
There was a rather even distribution of pattern types among the dry specimens. The dry skull specimens which were used as a comparison study had, however, the same pattern types as found in the living subjects.

The findings of Ritchey and Orban (1953) on the shape of the alveolar crests were confirmed.

The large incidence of irregular patterns and patterns having relatively few trabeculae no doubt has resulted in misinterpretation and misdiagnosis of pathology. Specifically, subtype IA has relatively few trabeculae throughout the alveolar processes of the maxilla and mandible and is similar in appearance to an osteoporosis. Subtype II B has numerous trabeculae and a lace-like pattern and is similar in appearance to a hyperparathyroidism. Stafne (1950) and Sicher (1947) describe the ground glass or marble type of bone characteristic of hyperparathyroidism. Therefore, more critical evaluations of radiographs must be made to avoid a misdiagnosis. A radiograph must be studied in the same manner as a histologic section to be interpreted correctly. A diagnosis or interpretation cannot be made from isolated negatives from a complete full mouth x-ray.

Other clinical applications are in order. For instance the problem of the orthodontist to determine whether a patient is a
risk or not as regards bone architecture must rest on the recognition or typical patterns. Therefore, this investigation should lead to a more critical analysis of radiographs in question and future surveys will be made possible through comparison of pattern types with orthodontic success or failure. The same considerations are valid for correlation of bone types with periodontal disease.

The ability of the dental practitioner to diagnose and interpret radiographs for clinical application is enhanced by this investigation. Since this investigation did not include a histologic study, there is no way to measure the size of individual trabeculae and the true size of marrow spaces. Only an impression of marrow size can be obtained by comparison of the number of trabeculae on the x-ray negative which is actually a view of a three dimensional field in one plane.
CHAPTER VI
SUMMARY AND CONCLUSIONS

1. A group of sixty-four male individuals (20-30 years of age) with full dentition, were examined roentgenologically in order to ascertain the possible types of distribution and arrangement of spongiosa in the alveolar processes of the maxilla and mandible.

2. In order to compare findings in this closed group with individuals of the average population, the jaws of twenty dry skulls, mostly of East Asiatic origin of both sexes and a wide range of age, were examined.

3. In the living as well as in the sample of skulls two distinct patterns of the architecture of the spongiosa were found.

4. The first type shows a regular horizontal arrangement of the spongy trabeculae running from the walls of the socket of one tooth or root to the next.

5. The second type shows an arrangement of spongiosa trabeculae that is irregular but is characterized by the much greater number of trabeculae in any specific area of the alveolar process.
6. Type I, as well as Type II, showed a variation in thickness of trabeculae and size of marrow spaces. This variability allows the division of each type into two subtypes, however, there are some individuals in whom the division into subtypes is difficult if not arbitrary.

7. The architecture in type I fits well into the general idea of trajectorial pattern of spongy bone.

8. Type II though evidently functionally satisfactory, lacks apparent trajectorial pattern which seems to be compensated by the greater number of trabeculae in any given area.

9. The functional architecture, the trajectories and pillars of mandible and maxilla, is constant and not influenced by variations in the spongiosa pattern of the alveolar processes.

10. The presence of two rather widely different patterns in the spongiosal architecture of the alveolar processes necessitates great caution in the diagnosis of skeletal pathologies from intraoral dental roentgenograms.
BIBLIOGRAPHY


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*Semidiagrammatic illustration of trabecular pattern I A.*
FIGURE II

Complete roentgenogram of trabecular pattern I A.
Semidigrammatic illustration of trabecular pattern I B.
Complete roentgenogram of trabecular pattern I B.
Semidiagrammatic illustration of trabecular pattern II A.
Complete roentgenogram of trabecular pattern II A.
FIGURE VII

Semidiagrammatic illustration of trabecular pattern II B.
Complete roentgenogram of trabecular pattern II B.
The thesis submitted by Dr. Nicholas J. Brescia has been read and approved by three members of the Departments of Anatomy and Oral Anatomy.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May 14, 1959

Harry Fischer
Signature of Adviser