THESIS
Dentistr
M.S.

CLEVELAND HEALTH SCIENCES LIBRARY
HEALTH CENTER LIBRARY

RADIOGRAPHIC ANATOMY OF THE CRANIOFACIAL COMPLEXES OF THE RAT, GUINEA PIG AND RABBIT

by

JACKIE BERKOWITZ

Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

Department of Orthodontics

School of Dentistry

CASE WESTERN RESERVE UNIVERSITY

June, 1975

CASE WESTERN RESERVE UNIVERSITY

GRADUATE STUDIES

We hereby approve the thesis of

JACKIE BERKOWITZ

candidate for the MASTER OF SCIENCE

degree.

Signed: Lyle E. Thurston Jr
(Chairman)

Joel Weintraub

W. Holly Donabedian

Sanford Neuger

Date May 31, 1975

75-65

7673 7-73

RADIOGRAPHIC ANATOMY OF THE CRANIOFACIAL COMPLEXES

OF THE RAT, GUINEA PIG AND RABBIT

Abstract

by

JACKIE BERKOWITZ

The details of human cephalometric radiographs have been characterized well enough to make the technique useful, both in the laboratory and the clinic. Of necessity, however, much experimentation must be done on non-human material. Unfortunately, the basic radiographic anatomy (for the most common laboratory animals) has not yet been investigated systematically.

The purpose of this investigation was to provide craniofacial biologists with a detailed atlas of verified roentgen-cephalometric structures and landmarks for several common laboratory animals.

The observations were obtained from a series of adult rats, guinea pigs, and rabbits. For each animal, standard lateral cephalograms were obtained of sagittally-sectioned dry skulls. Each half skull was labeled progressively with a radioopaque paste which served to outline ridges, processes, sutures, foramina, and fossae. For use as a "control," the unlabelled half skull was also radiographed, and then compared with the radiographs of the labeled skull section. In addition, dissection was conducted on fixed sections for each species.

A detailed atlas of verified lateral radiographic anatomy for each animal was then compiled utilizing the data gained from the dissection and labeled radiographs.

ACKNOWLEDGEMENTS

The author wishes to extend his sincere appreciation to the following individuals:

Dr. Lysle E. Johnston, Jr., Associate Professor of Orthodontics and Chairman of the Department of Orthodontics, School of Dentistry, Case Western Reserve University--who, as my advisor, gave invaluable assistance, counsel and patience, and who, as Department Chairman, guided my intellectual development, maturity, and professional aspirations.

Dr. B. Holly Broadbent, Jr., Associate Clinical Professor of Dentofacial Morhphology, School of Dentistry, Case Western Reserve University--for his advice and thoughtfulness throughout my graduate education.

Dr. Sanford Neuger, Associate Clinical Professor of Orthodontics, School of Dentistry, Case Western Reserve University--for his guidance and advice, both through my undergraduate and graduate education.

Dr. Joel Wisotzky, Professor of Oral Biology and Medicine, and Director of Dental Research, School of Dentistry, Case Western Reserve University--for his assistance and interest.

Mr. Douglas Johnston--for his time and efforts in preparation of the excellent photography evident throughout this thesis.

Mr. Adolf Vozka--for his adept preparation of the sectioned skulls.

Miss Laura Leventhal--for her time and efforts with the artistic aspect of this thesis.

Dr. Howard Kossoff--for his more than generous advice in the writing of this thesis.

Mrs. Linda Nicholl--for her skill in the typing of this thesis.

My classmates, Drs. Behrents, Bernabei, Kossoff and Rhodes--for the privilege of growing together the past two years, as professionals and most of all as friends.

DEDICATED

TO

My wife, Wendy, for her love,
patience, and encouragement;

My children, for beautiful
futures;

My parents, for all their love
and sacrifices.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
DEDICATION	v
LIST OF TABLES	vii
LIST OF PLATES	viii
INTRODUCTION	1
REVIEW OF THE LITERATURE	2
METHODS	7
RESULTS	18
DISCUSSION	45
SUMMARY AND CONCLUSIONS	49
LITERATURE CITED	50
APPENDICES	57

LIST OF TABLES

Table		Page
I.	Major Anatomical References for Rat, Guinea Pig, Rabbit Utilized in the Present Study	13
II.	Anatomical References--Rat	14
III.	Anatomical References--Guinea Pig	16
IV.	Anatomical References--Rabbit	17
V.	Illustrative Format	18

LIST OF PLATES

Plate		Page
I	Cephalostat.	11
II	Rat Skull--Lateral Structures.	21
III	Rat Cephalogram--Lateral Structures.	22
IV	Rat Half-Skull--Sagittal Structures.	23
V	Rat Cephalogram--Sagittal Structures	24
VI	Guinea Pig Skull--Lateral Structures	25
VII	Guinea Pig Cephalogram--Lateral Structures	26
VIII	Guinea Pig Half-Skull--Sagittal Structures	27
IX	Guinea Pig Cephalogram--Sagittal Structures.	28
X	Rabbit Skull--Lateral Structures	29
XI	Rabbit Cephalogram--Lateral Structures	30
XII	Rabbit Half-Skull--Sagittal Structures	31
XIII	Rabbit Cephalogram--Sagittal Structures.	32
XIV	Rat Mandible--Medial	34
XV	Rat Mandible--Dorsal	34
XVI	Rat Mandible--Lateral.	36
XVII	Rat Mandible--Cephalogram.	36
XVIII	Guinea Pig Mandible--Medial.	38
XIX	Guinea Pig Mandible--Dorsal.	38
XX	Guinea Pig Mandible--Lateral	40
XXI	Guinea Pig Mandible--Cephalogram	40
XXII	Rabbit Mandible--Medial.	42

Plate		Page
XXIII	Rabbit Mandible--Dorsal.	42
XXIV	Rabbit Mandible--Lateral	44
XXV	Rabbit Mandible--Cephalogram	44
XXVI	Rat Skull--Dorsal.	59
XXVII	Rat Skull--Ventral	61
XXVIII	Guinea Pig Skull--Dorsal	64
XXIX	Guinea Pig Skull--Ventral.	66
XXX	Rabbit Skull--Dorsal	69
XXXI	Rabbit Skull--Ventral.	71

INTRODUCTION

Since its introduction over forty years ago the cephalogram bas become an important tool for both the orthodontist and the craniofacial biologist. For the clinician, it is an important aid in the initial formulation of diagnoses and treatment plans, and, subsequently, the monitoring of treatment. For the researcher, it is an instrument which makes possible a wide variety of longitudinal growth studies, both in humans and laboratory animals.

Radiographs, however, are two dimensional representations of three dimensional objects; as such, they are subject to a variety of limitations which have been the subject of extensive investigations. Errors associated with positioning, landmark-identification, tracing and measurement are, to a variable degree, an unavoidable part of the technique. However, ignorance is not, and it would seem that the radiographic anatomy of many commonly used laboratory animals has not been as well-characterized as for humans (Etter, 1955; Krogman and Sassouni, 1957; Yen, 1960).

The immediate objective of this investigation is to provide researchers in craniofacial biology with a detailed atlas of verified roentgen-cephalometric structures and landmarks for the rat, guinea pig, and rabbit.

REVIEW OF THE LITERATURE

Introduction

In 1931, Broadbent and Hofrath published independently a roentgenographic technique designed to yield reproducible radiographs of the head. The development of the "cephalometer" first permitted standardized head fixation and orientation relative to both film and source, and thus, made it possible to obtain accurate measurements from longitudinal radiograph series. In the ensuing years, the literature has featured innumerable cephalometric studies aimed at characterizing the growth of the human face. As employed clinically, the cephalogram can generally be used only to measure dimensional changes. However, in an attempt to clarify experimentally the mechanisms involved in craniofacial growth, an increasing number of investigators have turned to animal models. Unfortunately, the necessary radiographic anatomy--so well described for humans--is only incompletely understood for most common laboratory animals.

Human Cephalometrics

In contrast to animal cephalometric investigations, studies utilizing human radiographic data enjoy a number of distinct advantages. The basic osteology of the human cranio-facial skeleton has long been well known; so well known, in fact, that it would be trivial to try to document it. Moreover, sophisticated anthropometric

techniques and precise conventions have existed for over a century. Thus, it has proved relatively easy to develop a highly-refined roentgen-cephalometric technique for human material.

At first, it was possible to merely adopt a variety of anthropological measures utilizing the most obvious cephalometric points and planes. Gradually, additional landmarks peculiar to the cephalometric radiograph were described in detail. An encyclopedic compilation of conventional radiographic anatomy, anthropometric definitions and early cephalometric analyses was presented by Krogman and Sassouni (1957). Indeed, almost every shadow on the human cephalogram has been identified (see, for example, Yen, 1960; Marshall, 1970) and most have been employed in contemporary clinical analyses.

Because of its firm anatomical and anthropometric foundation, contemporary cephalometricians have been able to effect a considerable improvement in the overall accuracy of the technique. Recently, however, a number of workers have analyzed the relative magnitude of the various errors inherent in the technique. A consistent finding has been that errors in landmark location are by far the most important (Hatton and Grainger, 1958; Savara, Tracy and Miller, 1966; Miller, Savara and Singh, 1966). Indeed, Van der Linden (1971) has showed that a major portion of this error is related merely to inadequacies in the definition of a number of common landmarks. Thus, it may be seen that even a high degree of anatomical sophistication does not result in the elimination of error, but rather its reduction to a tolerable and well-characterized level.

Animal Cephalometrics

Over the past few decades, cranio-facial biologists have begun to use roentgenographic cephalometrics to evaluate the outcome of animal experiments. These studies have been relatively few in number and--perhaps as either a cause of an effect--the technical aspects are not nearly so well characterized as for humans; each investigator has had to develop an entire technique--from anatomy to landmark identification.

Head Orientation

If--initially--human cephalometric techniques were adopted rather than adapted from anthropology, the methods used in animal studies have also been borrowed and have proved to be even more derivative.

Perhaps the initial small-animal study to employ the cephalometric technique was conducted by Burr and Mortimer (1938). In order to radiograph the living rat, they introduced a complex mechanism modified after Broadbent's cephalometer. Later, Spence (1940), devised an instrument specifically to obtain lateral headfilms of the living rat.

In 1942, Jarabak, devised an attachment for the Broadbent-Bolton cephalometer that enabled him to take lateral and postero-anterior roentgenographs of the rat, guinea pig and monkey. Gans

and Sarnat (1951) adapted the Broadbent-Bolton cephalometer for serial cephalometric roentgenography in combination with metallic implants, in monkeys. Later, Selman and Sarnat (1953, 1955, 1957), developed a headholder and utilized the combination of metallic implants and ventrodorsal serial cephalograms to examine growth at the frontonasal sutures of rabbits. Robinson and Sarnat (1955) used a comparable implant and technique with lateral radiographs in pigs. In order to examine the effects of sutural expansion Debbane (1958) devised a headholder for use with cats.

While craniofacial biologists have been able to adapt existing hardware for use with a wide variety of animals, the level of knowledge concerning craniofacial osteology, radiographic anatomy, and landmark identification in the most common laboratory animals is considerably below that for human studies.

Radiographic Anatomy

A strong case can be made that those who have applied the cephalometric method to laboratory animals have, to a degree, "placed the cart before the horse." Ideally, an analysis of data obtained from animal radiographs should at the very least, be based on a detailed knowledge of the gross and radiographic anatomy of the animal under investigation. Yet, at present, such knowledge is either totally lacking or, short of being definitive for most of the common laboratory animals. As a result, the selection of animal models has often been based upon such criteria as cost, size, hardiness, or maturation rate, as opposed to biological relevance. Also, landmark selection,

has been routinely on the basis of reliability (measurement repeatability) rather than validity (degree of approximation to true physical values) (Savara, Tracy and Miller, 1966). Crossing shadows, overlapping lines, and variations in intensity serve as landmarks as each investigation is essentially forced to "invent" an entire cephalometric technique for every experiment. These compromises cannot help but hamper the ability of the craniofacial biologist to generate hypotheses and to evaluate the significance of his data.

For example, Moore (1966), in a study of facial growth in the albino rat, compared a variety of radiographic measurements with equivalent measurements taken directly from prepared skulls and found a disquieting lack of agreement. The problem, he felt, was that for certain measurements, radiographic landmarks could not be identified with any real degree of certainty, and that this uncertainty required modification of the craniometric definitions. Cleall, Wilson and Garnett (1968), investigated normal craniofacial growth in the rat and concluded that, among other things, their cephalometric analysis was unreliable, due to the difficulty of locating cephalometric landmarks accurately on photographic prints.

It should not be inferred from the foregoing that existing animal studies have been conducted in complete ignorance but, rather, that a lack of basic systematic anatomical knowledge has served to limit their scope and cloud their interpretation.

It will be the purpose of this investigation to provide an atlas of detailed verified radiographic anatomy for three species of animal--rat, guinea pig, rabbit--commonly employed in craniofacial research.

METHODS

Sample

The present investigation involved three species of laboratory animal commonly utilized by craniofacial biologists:

1. Sprague-Dawley Norway rats, Rattus norvegicus, purchased from Zivic-Miller Laboratory (Allison Park, Pennsylvania), from stock designation, ZML: ZM(SD)BR.

2. Hartley guinea pigs, Cavia porcellus, supplied from stock, CWR: (HA), from the Animal Facilities Department, Case Western Reserve University, Cleveland, Ohio.

3. New Zealand White rabbits, Oryctolagus cuniculus, stock designation LAH: (NZW), purchased from Laboratory Animals, Akron, Ohio.

General Description

Standardized radiographs of the rat, guinea pig, and rabbit in norma lateralis were obtained with the aid of a specially constructed cephalostat. For each species, standard lateral radiographs were obtained of sagittally-sectioned dry skulls. Each half-skull was labeled progressively and systematically with a radioopaque paste consisting of vaseline and amalgam filings (Spher-a-loy, Kerr Sybron Corporation, Romulus, Michigan). This paste was painted along processes of various bones, onto bony ridges, in foramina, around fossae, and across sutures. The labeled skulls were radiographed repeatedly and used to identify the various landmarks seen in the initial unmarked films (Yen, 1960). Emphasis was placed on the

identification of landmarks which appeared to have a high probability of being technically reliable and biologically significant.

To clarify and illustrate the basic anatomy represented in the radiographs, gross dissection of formalin-fixed specimens was performed utilizing anatomical texts as references. These dissections were then correlated with corresponding radiographs in order to locate precisely various soft and hard tissue structures of potential utility in cephalometric research. This facilitated the localization and identification of various soft tissue structures, for example, the pituitary gland and nasal septal cartilage, both of which are destroyed in the preparation of dry skulls. This procedure served to clarify the spatial relationship between and among a variety of hard and soft tissues. For example, the position of the pituitary gland relative to the cranial base was accurately delineated, and the relation of the septal cartilage to its surrounding hard tissues, such as the vomer and median plate of the ethmoid, was also observable.

Skull Preparation

Each of the animals was killed by an overdose of sodium pentobarbitol (Diabutal, Diamond Laboratories, Des Moines, Iowa), injected intraperitoneally. The heads were then severed and some of the soft tissues were cut away. Each was then placed in a liter flask containing 50 grams of an enzyme detergent (Biz, Procter and Gamble, Cincinnati, Ohio) and 50 ml of water, allowed to soak for six hours, and then boiled for two hours (Ossian, 1970).

At this time the skulls were removed from the solution and rinsed thoroughly under running water to aid in removing the remaining soft tissue. Tenacious fragments were removed by cutting and scraping with instruments. The skulls were then bleached for thirty minutes in a sodium hypochlorite (Clorox, The Clorox Company, Oakland, California) solution and air-dried.

The dried skulls of six rats, six guinea pigs and four rabbits were marked with a pencil line along the midsagittal plane, embedded in paraffin, and sectioned with a high speed steel circular saw (3 inch diameter by .010 inch thickness). The wax served to protect the delicate bony structures during sectioning. Half of the sections were parasagittal and half were sagittal. The paraffin was then removed by immersion in a hot wax bath (Vacuum Infiltrator, Upshaw Manufacturing Company, Detroit, Michigan), followed by a solution of xylene. The skulls were then allowed to air-dry.

Data Collection

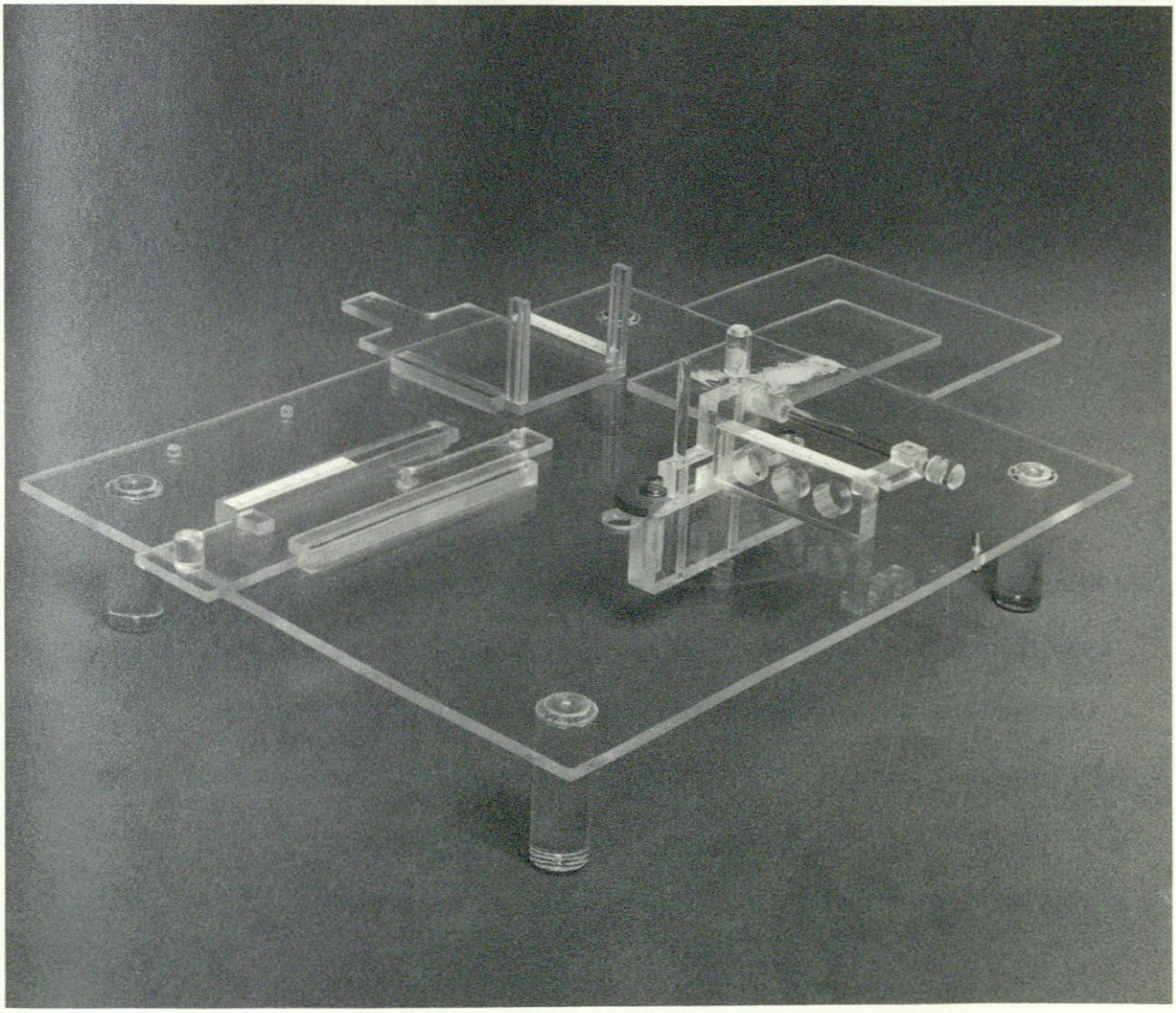
Cephalograms

A specially constructed cephalostat, similar to the one designed by Spence (1940), modified by Gange (1973) for the rat, and later modified by Fuller (1974) for the guinea pig, was used for the roentgenographic study. It featured adjustable ear rods, an incisal rest and a film holder (Plate I).

The cephalograms of the rats and guinea pigs were taken on standard dental occlusal film (Kodak, DF-46, Eastman Kodak Company,

PLATE I.--Cephalostat.

Features: Adjustable ear rods
Incisal rest
Film holder



Rochester, New York), exposed at 0.8 seconds at 15 mA and 90 kV. The radiographs of the rabbits were taken on 5 X 7 inch radiographic film (Kodak, BB-54, Eastman Kodak Company, Rochester, New York), again at 0.8 seconds, 15 mA and 90 kV. A standard dental radiographic unit was employed (General Electric, Model 118CE8A, Milwaukee, Wisconsin). To insure technical consistency, all the films were developed in an automatic film processor (Auveloper, S.S. White Company, Great Neck, New York).

Radiographic Landmarks

The resulting radiographs were enlarged to a uniform 3X magnification and printed on photographic paper. 2H pencil tracings were made on .003 inch frosted acetate of the photographic prints of the labeled cephalograms. A detailed composite of the verified landmarks for each animal was constructed in norma lateralis utilizing the data gained from an analyses of the radiographs in conjunction with the dissections.

Dissection

Considerable gross dissection was performed on two specimens from each species. These heads were fixed in 10% formalin and sectioned along the sagittal plane. They were never boiled so as to preserve intracranial soft tissue.

The dissection was carried out at magnifications up to 7X under a binocular dissecting microscope. Detailed anatomical texts and manuals assisted in verifying the gross anatomy of each of the experimental animals (Tables I, II, III, IV).

TABLE I

MAJOR ANATOMICAL REFERENCES FOR RAT, GUINEA PIG, RABBIT UTILIZED IN THE PRESENT STUDY

Investigator	Year	Source	Animal
Martin and Moale	1895	Text	Rat
Alezais	1899	Journal Article	Guinea Pig
Greene	1935	Text	Rat
Ballard	1937	Ph.D. Thesis	Guinea Pig
Farris and Griffith	1942	Text	Rat
Pitel	1947	M.S. Thesis	Guinea Pig
Whitehouse and Grove	1947	Text	Rabbit
Craigie	1948	Text	Rabbit
Chiasson	1958	Dissection Manual	Rat
Schumacher and Rehmer	1962	Journal Article	Guinea Pig
Craigie	1966	Dissection Manual	Rabbit
Vinogradov and Argiropulo	1968	Text	Rat Guinea Pig
McLaughlin	1970	Dissection Manual	Rabbit
Simmons and Brick	1970	Text	Mouse

TABLE II

ANATOMICAL REFERENCES--RAT

Investigator	Year	Structures Studied
Strong	1925	Skull
Mortimer	1937	Skull
Burr and Mortimer	1938	Skull
Spence	1940	Skull
Pratt	1943	Skull
Horowitz and Shapiro	1951	Mandible
Massler and Schour	1951	Cranial Vault
Moss	1954	Calvaria
Horowitz and Shapiro	1955	Skull
Moss and Baer	1956	Skull
Mohammed	1957	Maxilla
Moss	1958	Cranial Vault
Gardner, Dasler and Weinmann	1958	Mandible
Ford and Horn	1959	Skull
Young	1959	Skull
Moss	1960	Calvaria
Dubrul and Laskin	1961	Sphenooccipital Synchondrosis
Asling and Frank	1963	Skull
Huelke and Castelli	1965	Mandible

TABLE II Continued

Investigator	Year	Structures Studied
Moore	1966	Skull
Simpson	1966	Mandible
Wright, Kjaer and Asling	1966	Skull
Hoyte	1967	Cranial Base
Cleall, Wilson and Garnett	1968	Skull
Hoyte	1968	Skull
Vilmann	1968	Parietal Bone
Retief and Dreyer	1969	Mandible
Vilmann	1969	Cranial Base
Wragg, Klein, Steinvorth and Warpeha	1970	Skull
Cleall, Jacobson, Chebib and Berker	1971	Skull and Mandible
Hoyte	1971	Cranial Vault and Base
Hoffman and Tade	1972	Mandible
Rayne and Crawford	1972	Skull
Vilmann	1972	Cranial Vault
Gange	1973	Midface

TABLE III

ANATOMICAL REFERENCES--GUINEA PIG

Investigator	Year	Structures Studied
Hoyte	1967	Cranial Base
Stenström and Thilander	1967	Skull
Hoyte	1968	Skull
Stenström and Thilander	1970	Skull
Hoyte	1971	Cranial Vault and Base
Rönning and Isotupa	1973	Skull
Belhobek	1974	Mandible
Fuller	1974	Mandible

TABLE IV

ANATOMICAL REFERENCES--RABBIT

Investigator	Year	Structures Studied
Selman and Sarnat	1955	Cranial Vault Sutures
Selman and Sarnat	1957	Frontonasal Suture
Erickson and Ogilvie	1958	Cranium and Mandible
Sawin, Ranlett and Crary	1959	Sphenooccipital Synchondrosis
Wexler and Sarnat	1961	Septovomeral Region
Isotupa, Koski and Mäkinen	1965	Cranial Vault Sutures
Sarnat and Shanedling	1965	Orbit and Upper Face
Wexler and Sarnat	1965	Nasal Septum
Sarnat and Wexler	1966	Nasal Septum
Hoyte	1967	Cranial Base
Sarnat and Wexler	1967a	Nasal Septum
Sarnat and Wexler	1967b	Nasal Septum
Hong, Yen and Shaw	1968	Cranial Vault
Hoyte	1968	Skull
Sarnat and Wexler	1968	Nasal Septum
Moore and Spence	1969	Cranial Base
Sarnat and Wexler	1969	Nasal Septum
Sarnat	1970	Septovomeral Region
Hoyte	1971	Cranial Vault and Base

RESULTS

The results of this investigation are presented on Plates II through XXV, the organization of which is summarized in Table V.

TABLE V

ILLUSTRATIVE FORMAT

Animal	Item	Plate Number	Page
Rat	Whole skull--Lateral structures	II	21
	Cephalogram--Lateral structures	III	22
	Half-skull--Sagittal structures	IV	23
	Cephalogram--Sagittal structures	V	24
	Mandible--Medial	XIV	34
	Mandible--Dorsal	XV	34
	Mandible--Lateral	XVI	36
	Mandible--Cephalogram	XVII	36
	Skull--Dorsal	XXVI	59
	Skull--Ventral	XXVII	61
Guinea Pig	Whole skull--Lateral structures	VI	25
	Cephalogram--Lateral strcutures	VII	26
	Half-skull--Sagittal structures	VIII	27
	Cephalogram--Sagittal structures	IX	28
	Mandible--Medial	XVIII	38
	Mandible--Dorsal	XIX	38
	Mandible--Lateral	XX	40
	Mandible--Cephalogram	XXI	40
	Skull--Dorsal	XXVIII	64
	Skull--Ventral	XXIX	66

TABLE V continued

Animal	Item	Plate Number	Page
Rabbit	Whole skull--Lateral structures	X	29
	Cephalogram--Lateral structures	XI	30
	Half-skull--Sagittal structures	XII	31
	Cephalogram--Sagittal structures	XIII	32
	Mandible--Medial	XXII	42
	Mandible--Dorsal	XXIII	42
	Mandible--Lateral	XXIV	44
	Mandible--Cephalogram	XXV	44
	Skull--Dorsal	XXX	69
	Skull--Ventral	XXXI	71

The format is as follows:

1. Labeled photographs of prepared skulls are presented in register with similarly-labeled lateral cephalograms. For each species, cephalograms are coordinated separately with photographs of lateral and sagittal structures.

2. Coordinated, labeled cephalograms and photographs--dorsal, medial, lateral--for the mandibles alone.

This layout permits the reader to compare directly the gross and radiographic appearance of a wide variety of structures. The juxtaposition of a labeled lateral photograph with a labeled cephalogram, and a labeled sagittal photograph with a labeled cephalogram, should prove of benefit in utilizing the illustrative material presented here. In conjunction with the photographs and cephalograms, a fold-out list of abbreviations

has been included in Appendix VI, pp. 74.

In addition, dorsal and ventral photographs of the skulls for each species are presented in Appendix I, II, and II (Plates XXVI-XXXI). These gross anatomical views will serve the reader to visualize precisely some of the radiographic landmarks.

PLATE II.--Rat Skull--Lateral Structures

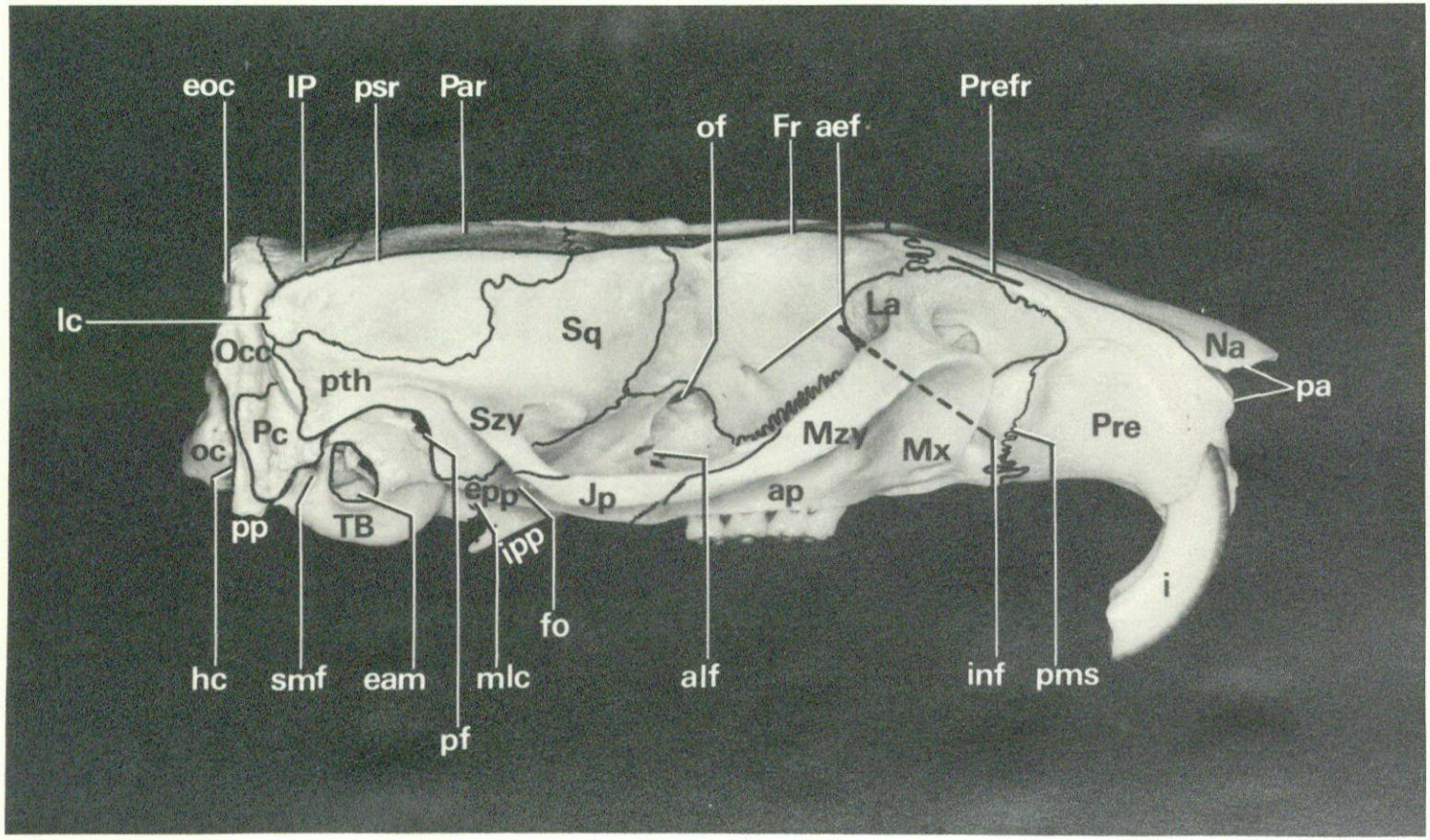


PLATE III.--Rat Cephalogram--Lateral Structures

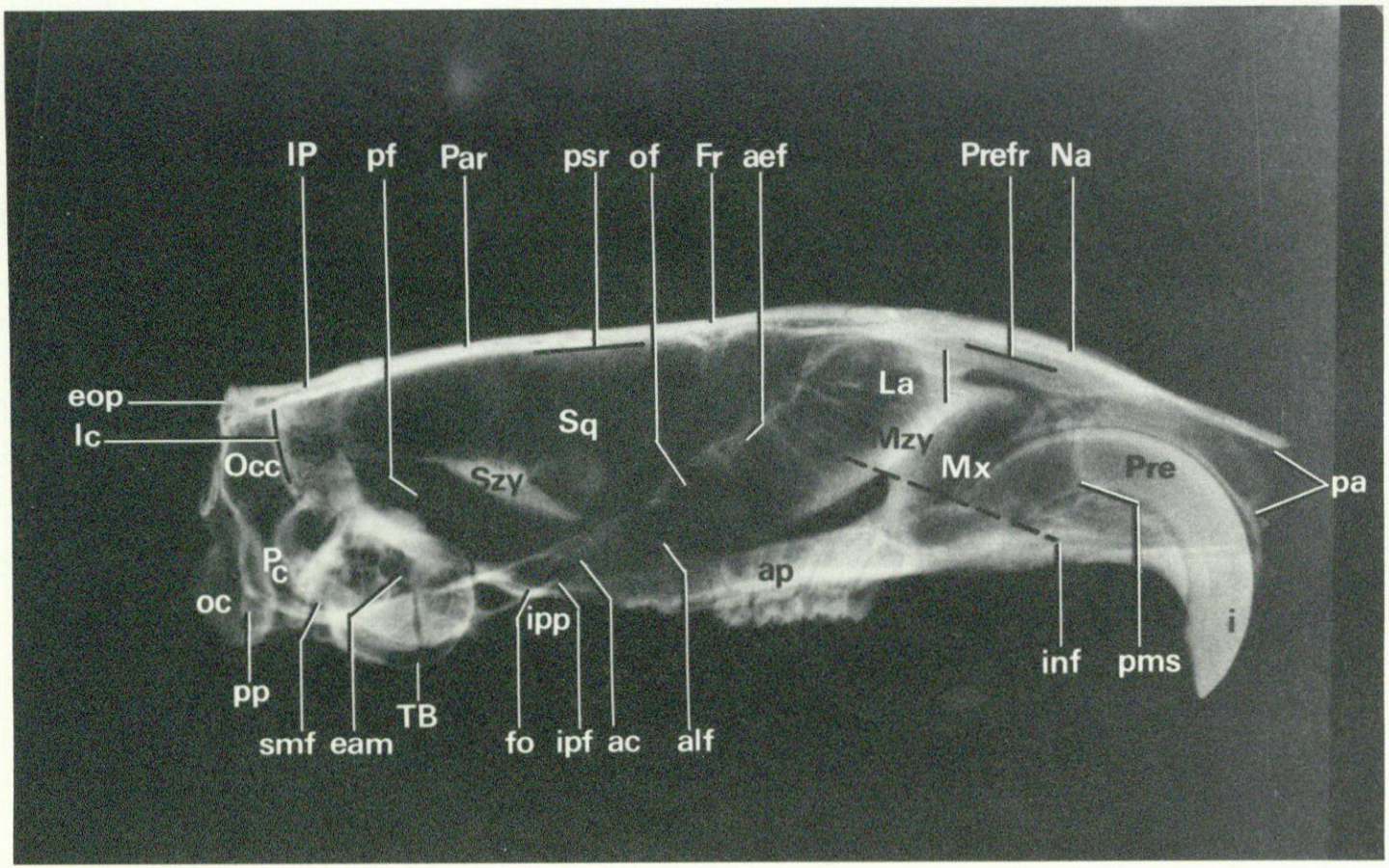


PLATE IV.--Rat Half-Skull--Sagittal Structures

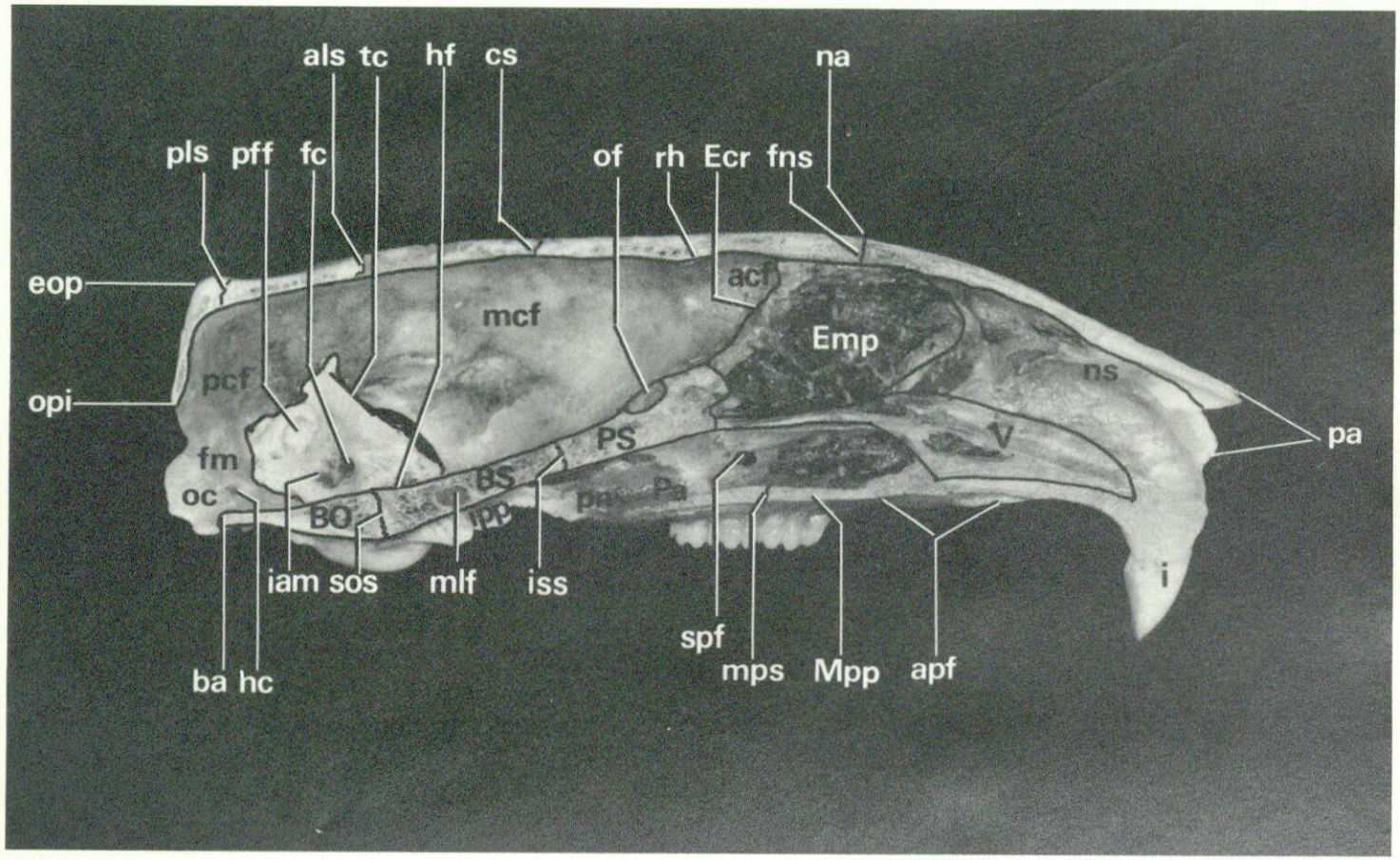


PLATE V.--Rat Cephalogram--Sagittal Structures

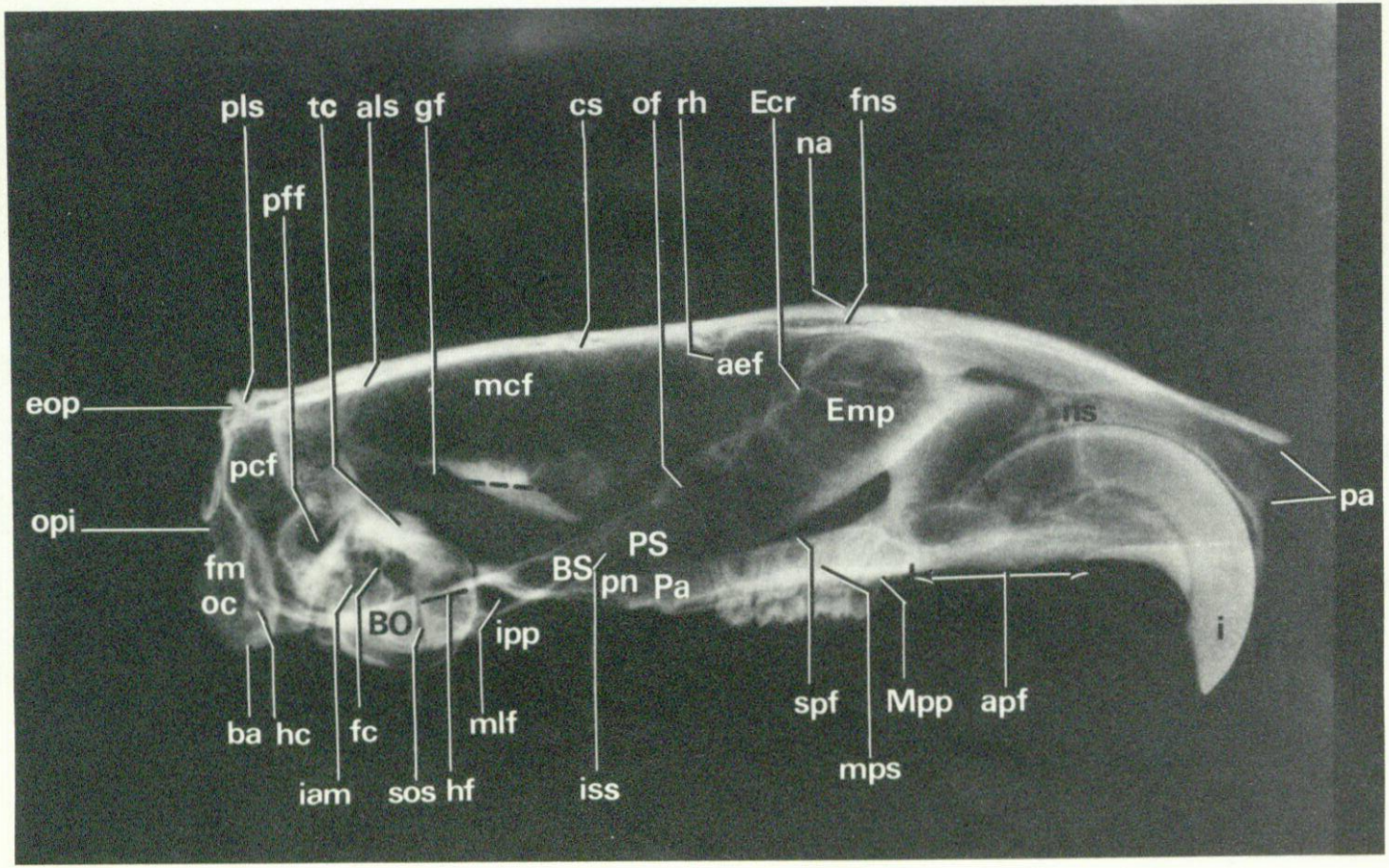
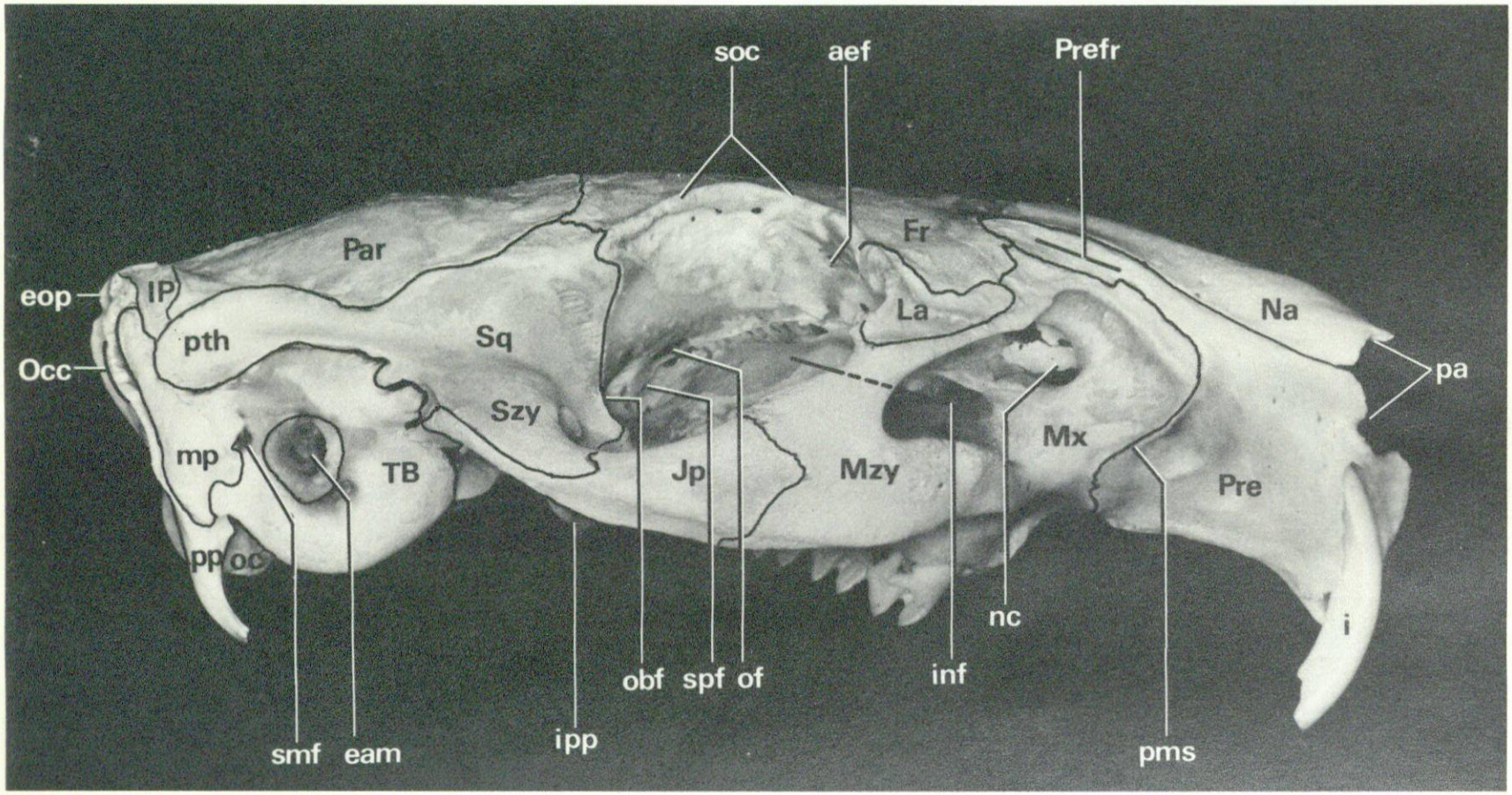


PLATE VI.--Guinea Pig Skull--Lateral Structures



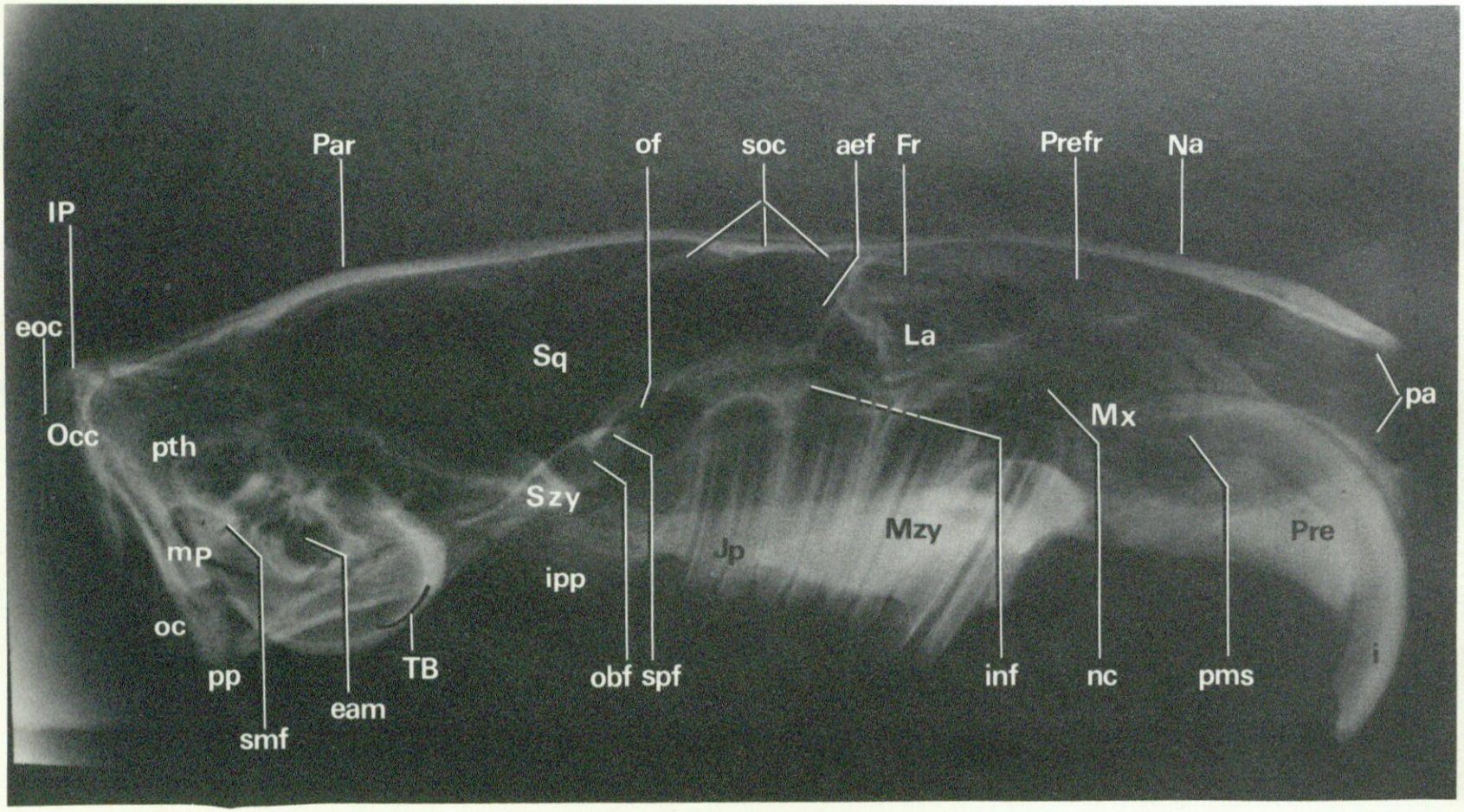
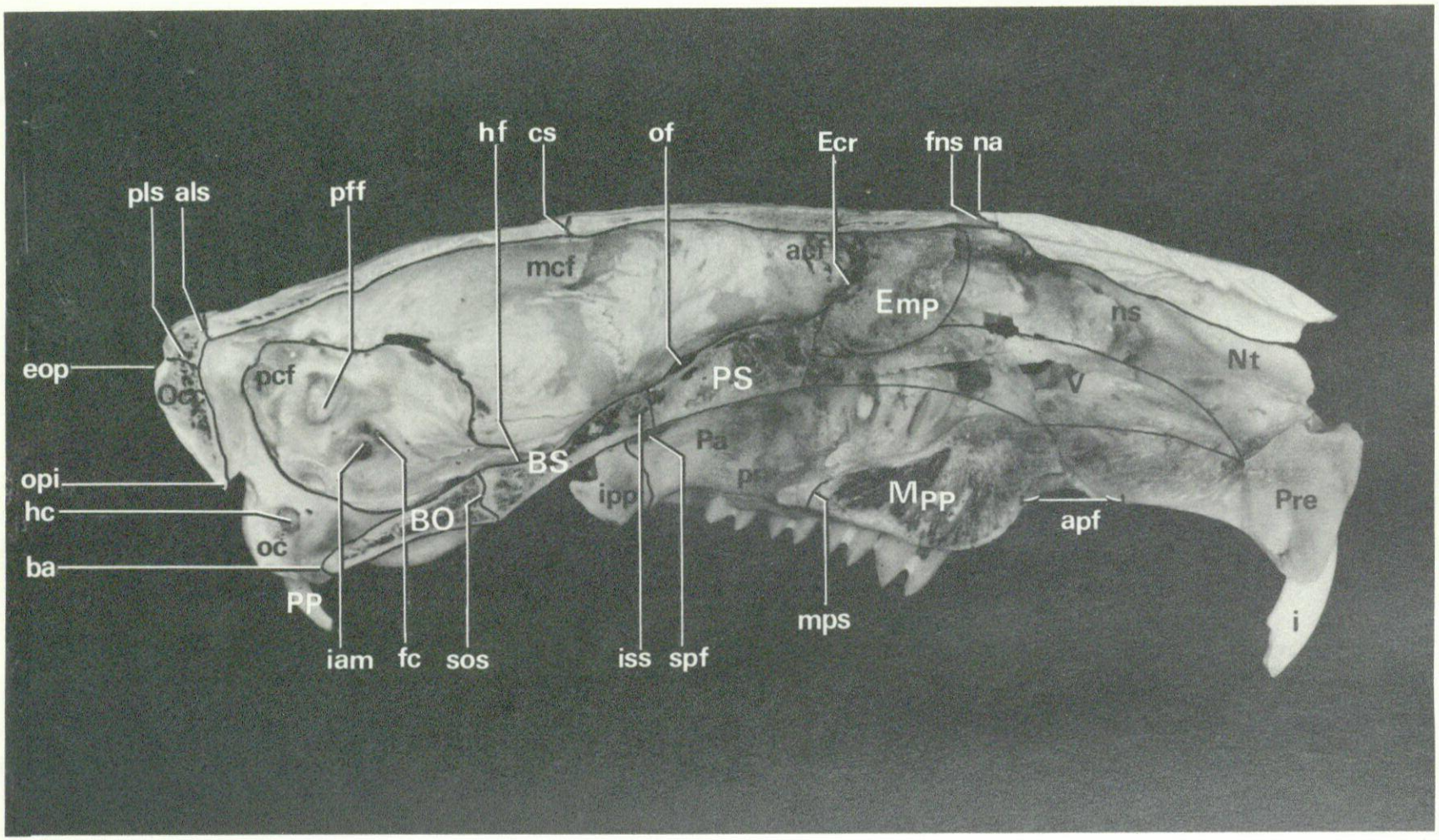


PLATE VII.--Guinea Pig Cephalogram--Lateral Structures

PLATE VIII.--Guinea Pig Half-Skull--Sagittal Structures



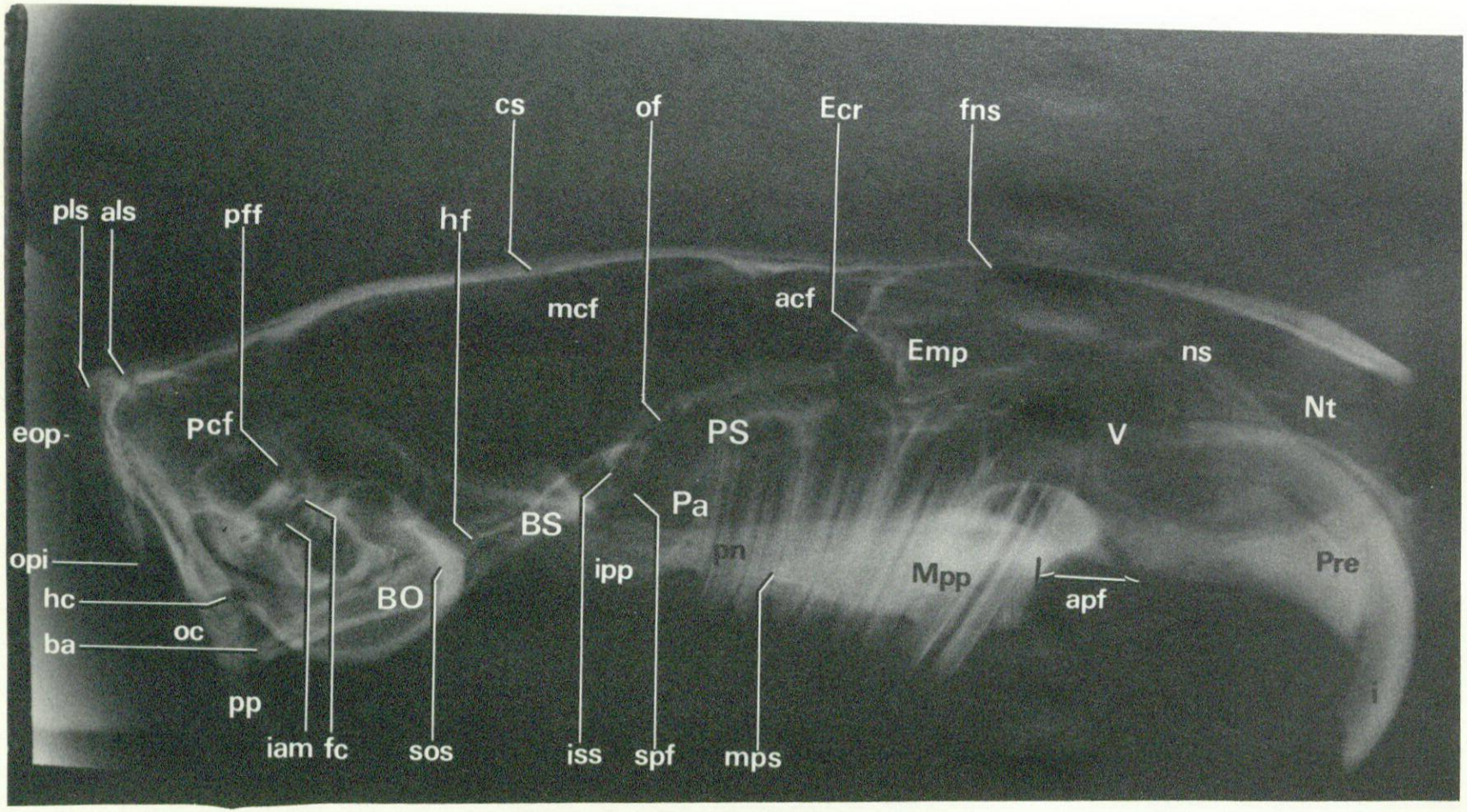


PLATE IX.--Guinea Pig Cephalogram--Sagittal Structures

PLATE X.--Rabbit Skull--Lateral Structures

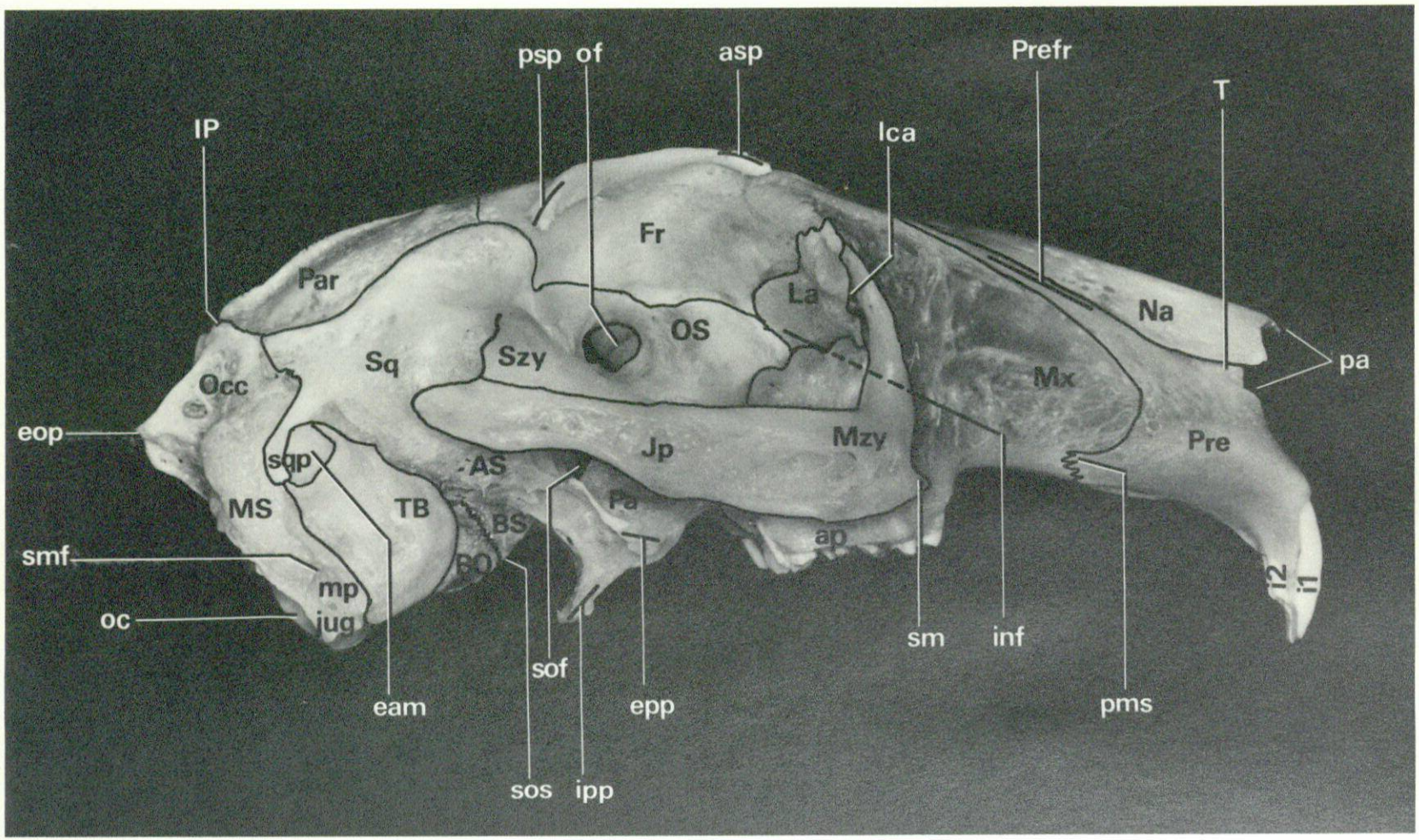


PLATE XI.--Rabbit Cephalogram--Lateral Structures

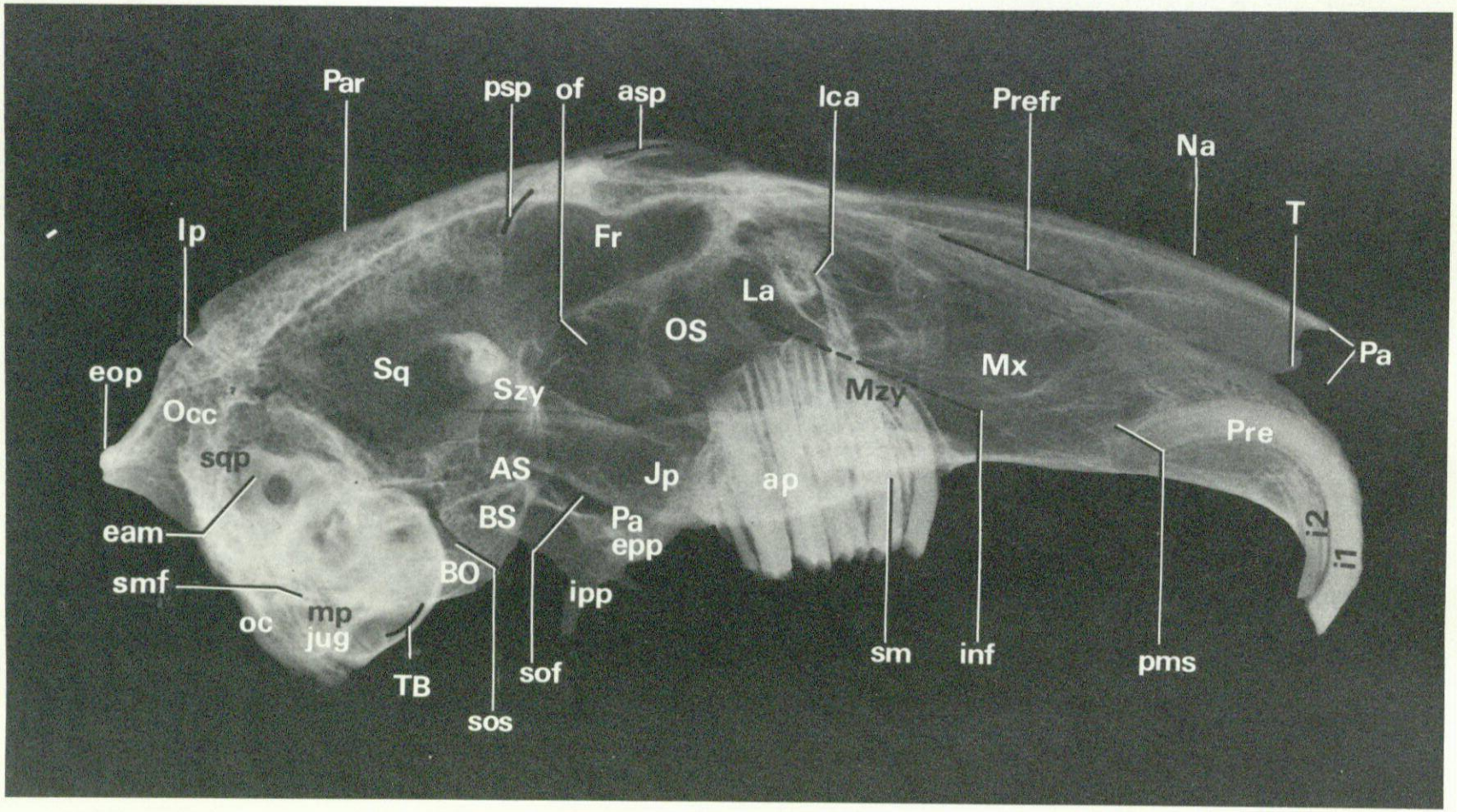


PLATE XII.--Rabbit Half-Skull--Sagittal Structures

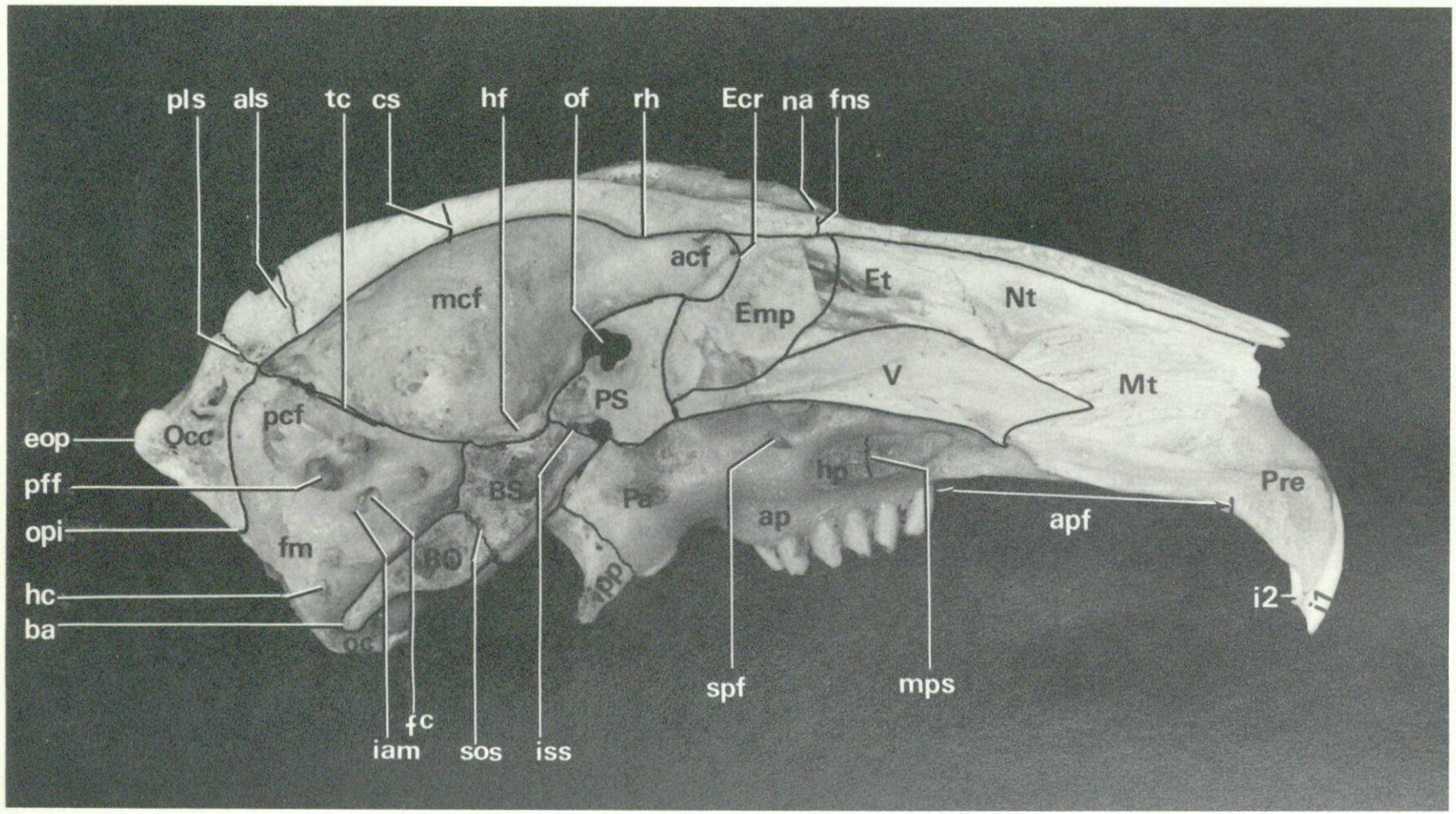


PLATE XIII.--Rabbit Cephalogram--Sagittal Structures

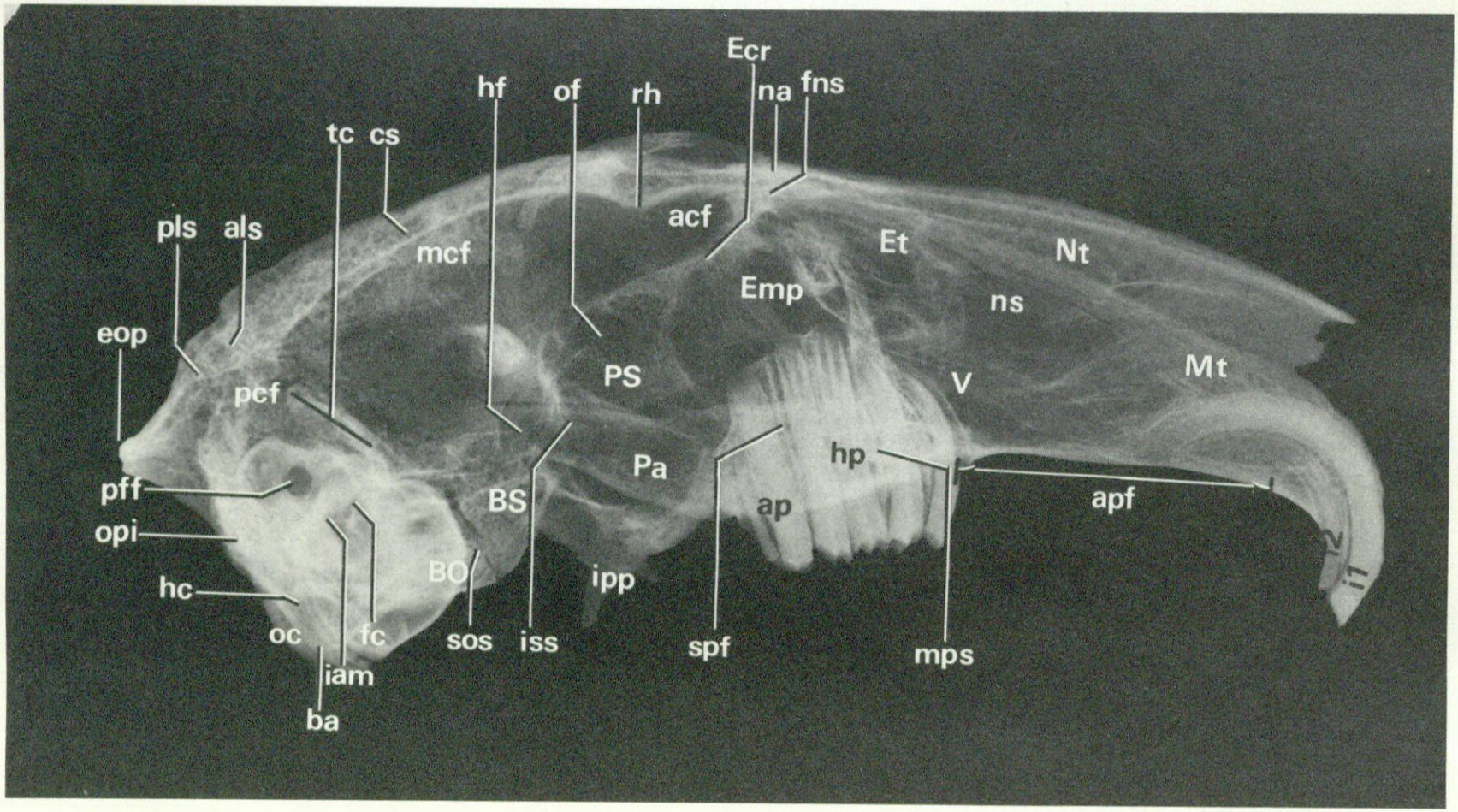
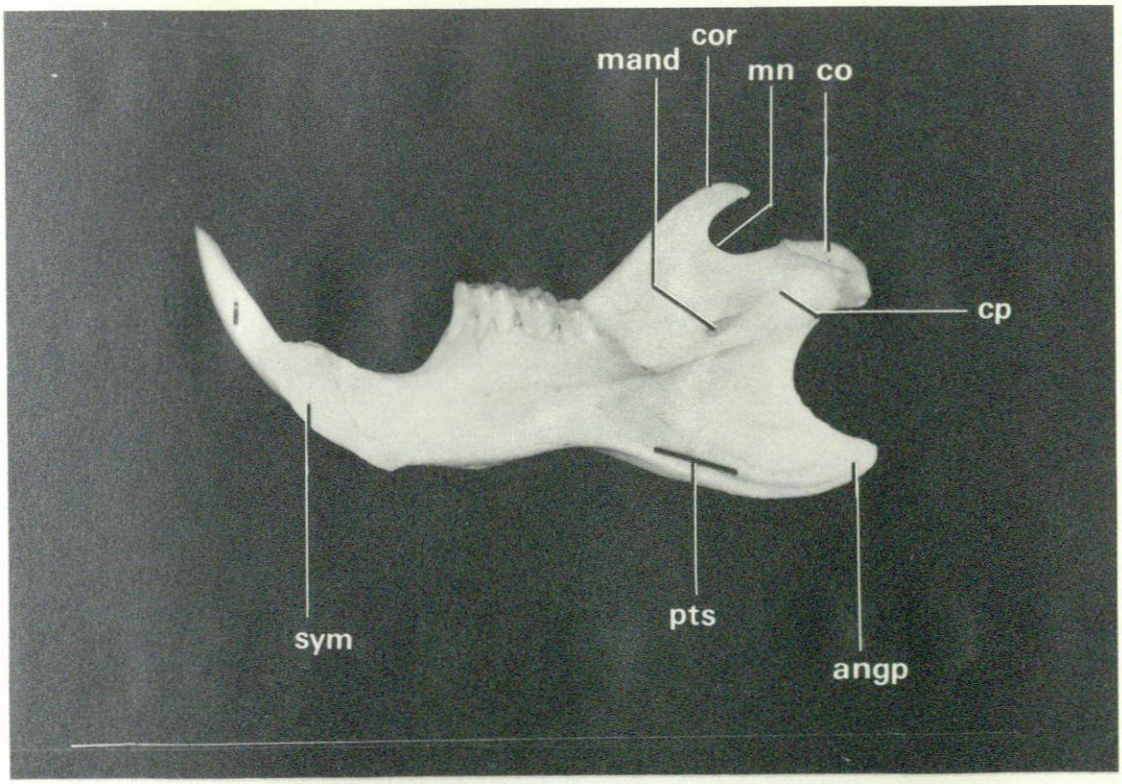


PLATE XIV.--Rat Mandible--Medial

angp = angular process
co = condyle
cor = coronoid process
cp = condyloid process
i = incisor
m1, m2, m3 = molars
mand = mandibular foramen
men = mental foramen
mn = mandibular notch
pts = pterygoid shelf
sym = symphysis

PLATE XV.--Rat Mandible--Dorsal


cor
mand
mn
co
cp
sym
pts
angp

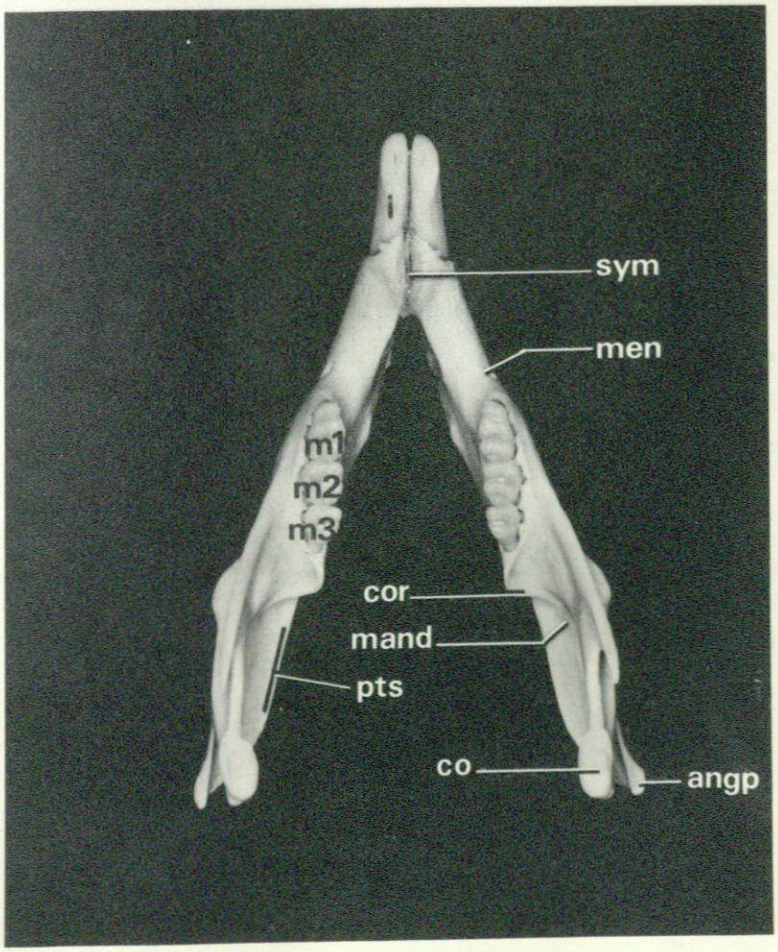
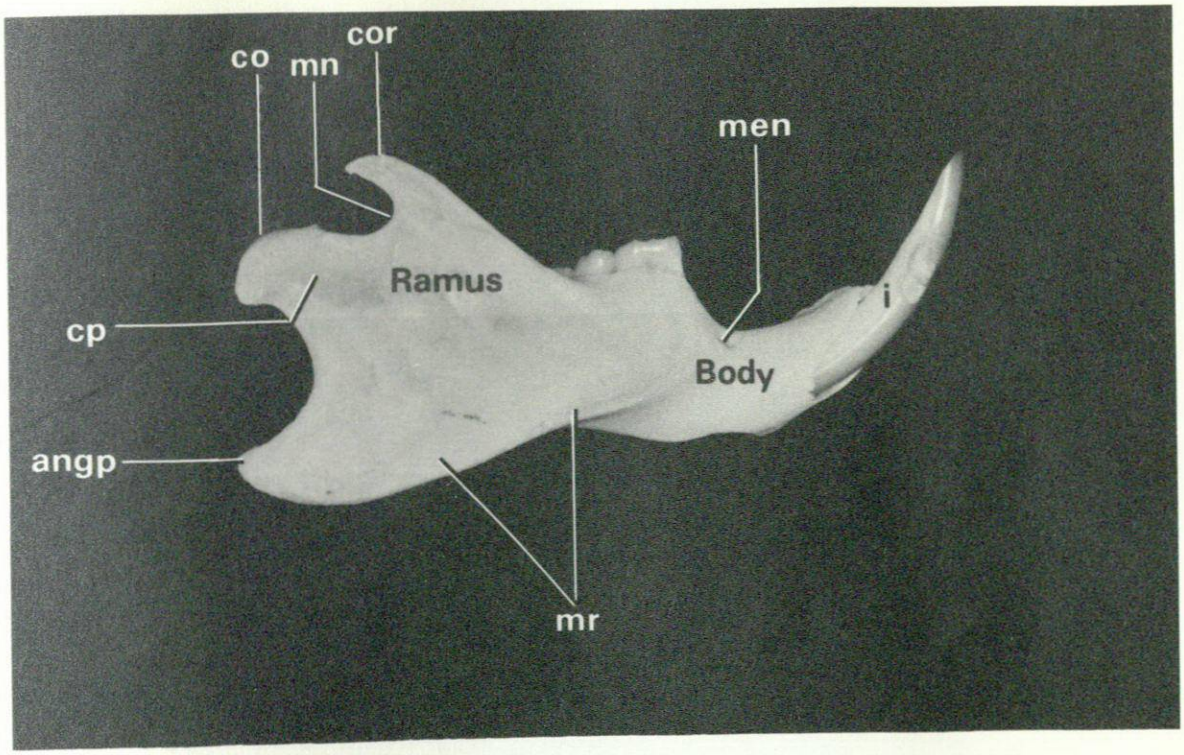

sym
men
m1
m2
m3
cor
mand
pts
co
angp

PLATE XVI.--Rat Mandible--Lateral

angp = angular process
body = body
co = condyle
cor = coronoid process
cp = condyloid process
i = incisor
m1, m2, m3 = molars
mand = mandibular foramen
men = mental foramen
mn = mandibular notch
mr = masseteric ridge
pts = pterygoid shelf
ramus = ramus
sym = symphysis

PLATE XVII.--Rat Mandible--Cephalogram


co
mn
cor
men
Ramus
i
cp
Body
angp
mr

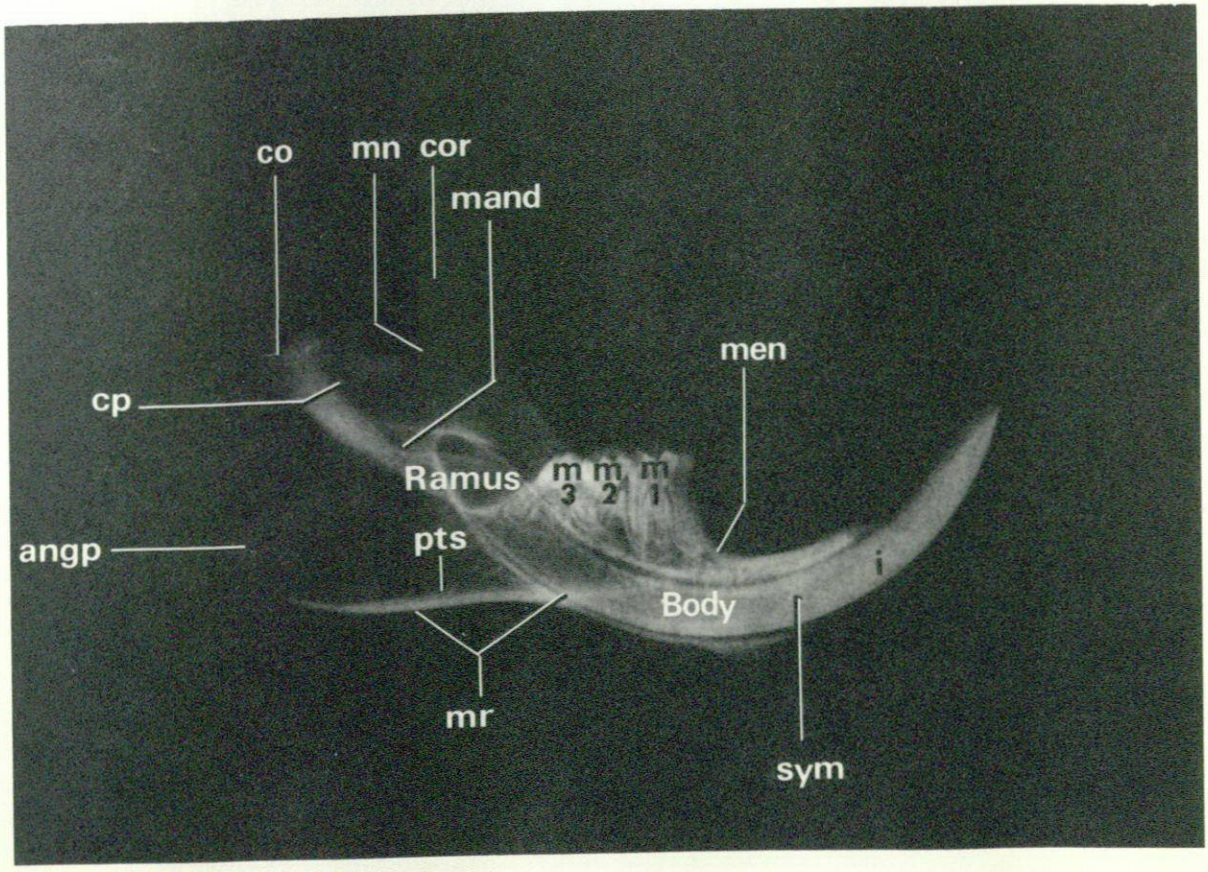
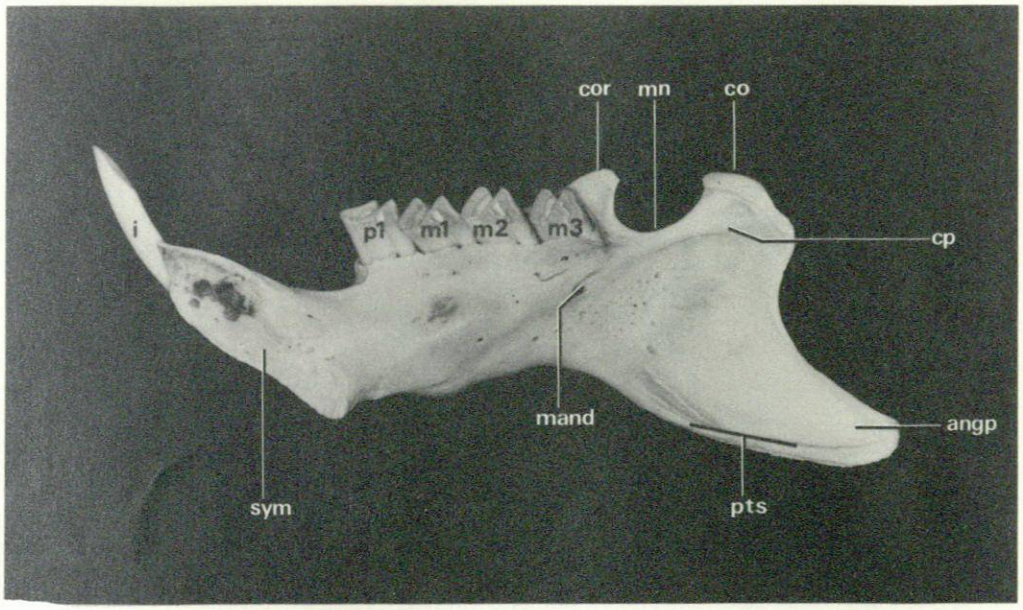

co
mn
cor
mand
men
cp
Ramus
m3
m2
m1
angp
pts
i
Body
mr
sym

PLATE XVIII.--Guinea Pig Mandible--Medial

angp = angular process
co = condyle
cor = coronoid process
cp = condyloid process
eoc = external oblique crest
i = incisor
m1, m2, m3 = molars
mand = mandibular foramen
men = mental foramen
mn = mandibular notch
mr = masseteric ridge
pl = premolar
pts = pterygoid shelf
sym = symphysis

PLATE XIX.--Guinea Pig Mandible--Dorsal


cor
mn
co
i
p1
m1
m2
m3
cp
mand
angp
sym
pts

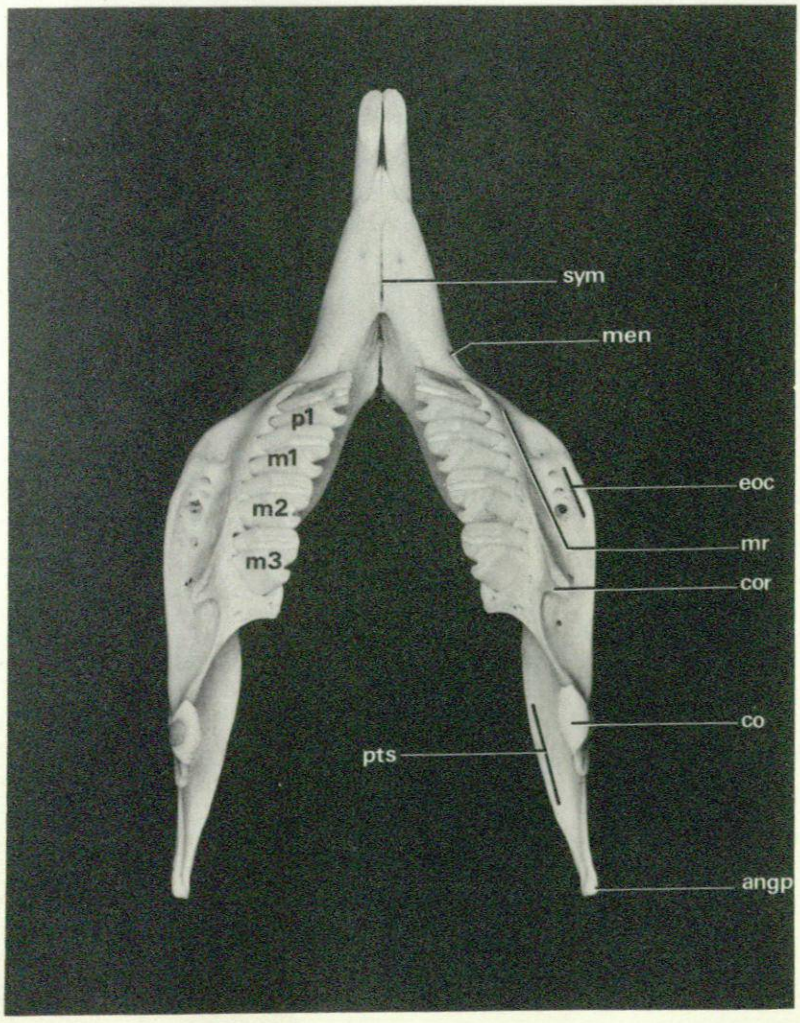
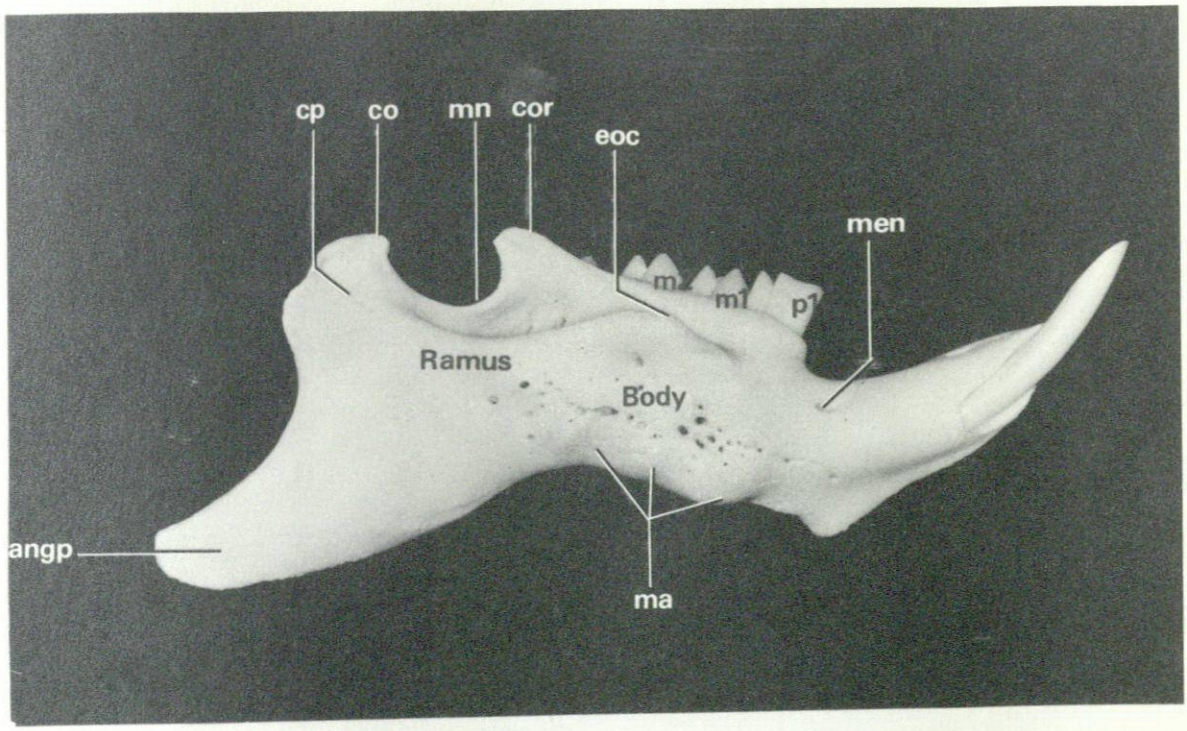

sym
men
p1
m1
m2
m3
eoc
mr
cor
co
pts
angp

PLATE XX.--Guinea Pig Mandible--Lateral

angp = angular process
body = body
co = condyle
cor = coronoid process
cp = condyloid process
eoc = external oblique crest
i = incisor
m1, m2, m3 = molars
ma = molar alveolus
mand = mandibular foramen
men = mental foramen
mn = mandibular notch
pl = premolar
pts = pterygoid shelf
ramus = ramus
sym = symphysis

PLATE XXI.--Guinea Pig Mandible--Cephalogram


cp
co
mn
cor
eoc
men
m2
m1
p1
Ramus
Body
angp
ma

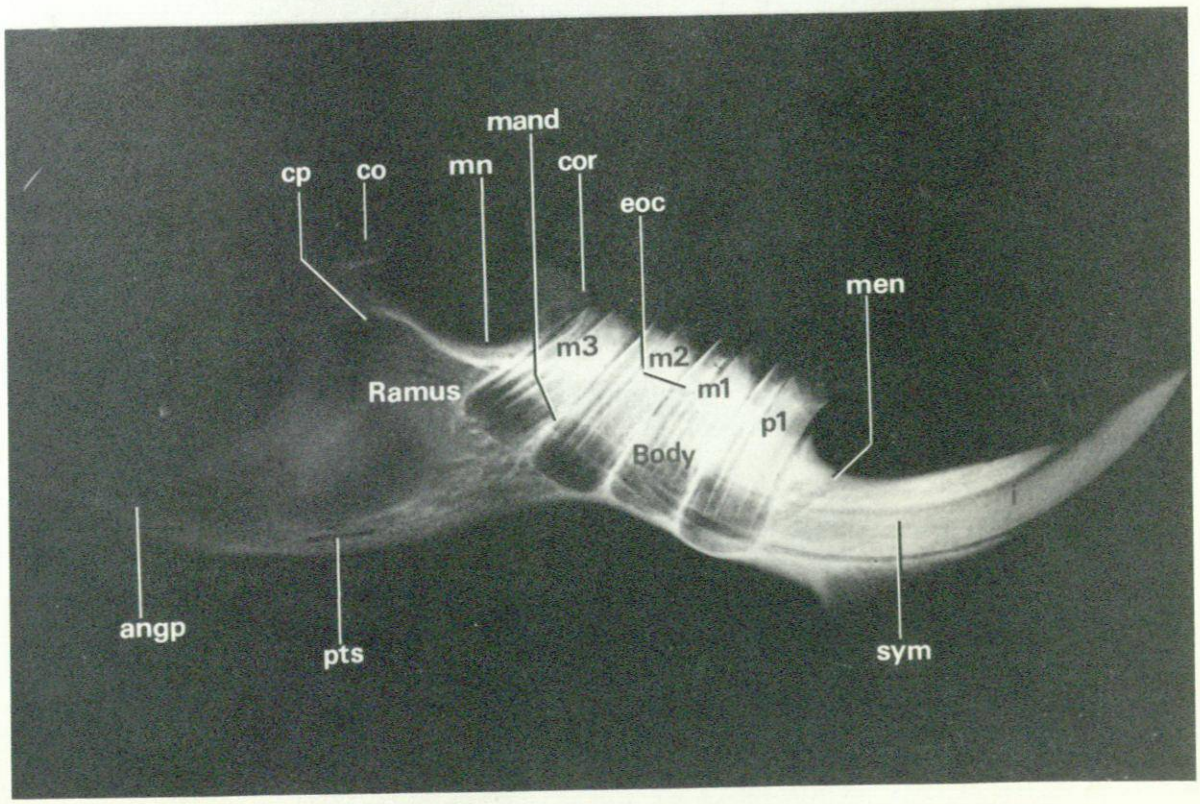
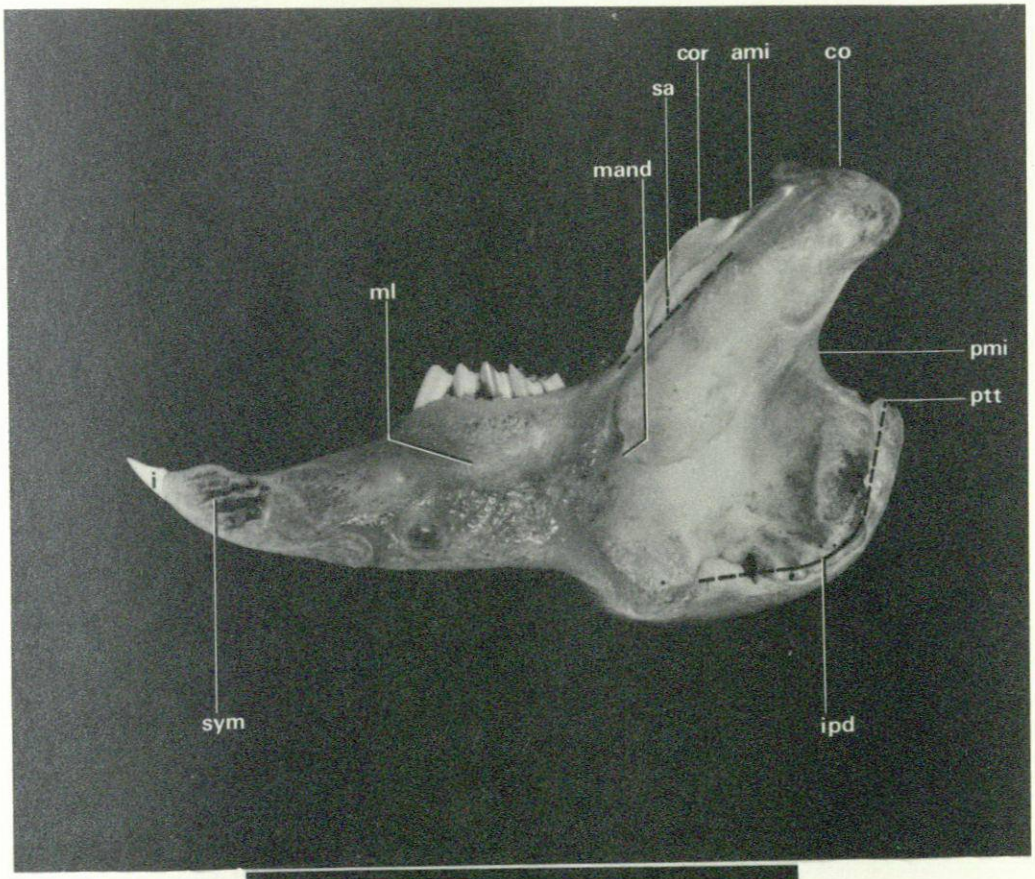

mand
cp
co
mn
cor
eoc
men
m3
m2
m1
p1
Ramus
Body
angp
pts
sym

PLATE XXII.--Rabbit Mandible--Medial

ami = anterior mandibular incisure
avf = anastomostic vein foramen
co = condyle
cor = coronoid process
i = incisor
ipd = inferior pterygoid depression
m1, m2, m3 = molars
mand = mandibular foramen
mas = masseteric tuberosity
men = mental foramen
mf = masseteric fossa
ml = mylohyoid line
p1, p2 = premolars
pmi = posterior mandibular incisure
ptt = pterygoid tuberosity
sa = sulcus ascendens
sym = symphysis

PLATE XXIII.--Rabbit Mandible--Dorsal


cor
ami
co
sa
mand
ml
pmi
ptt
i
sym
ipd

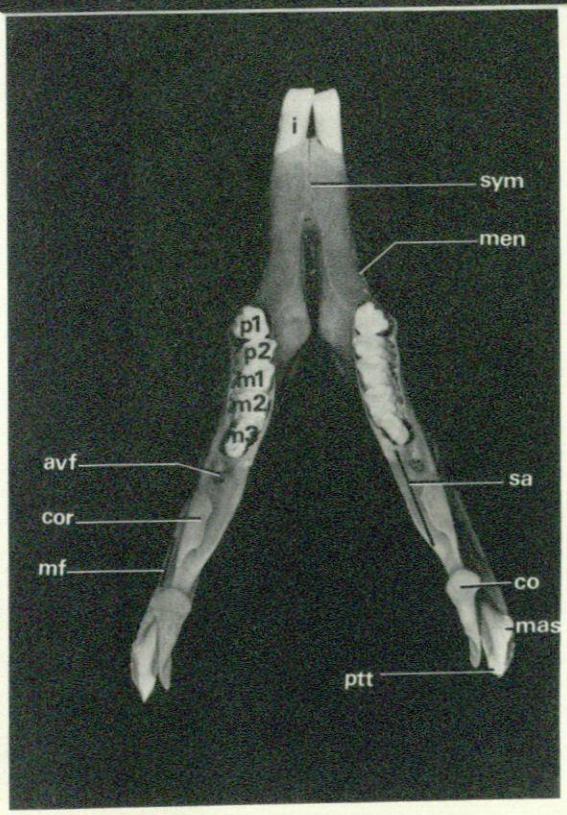
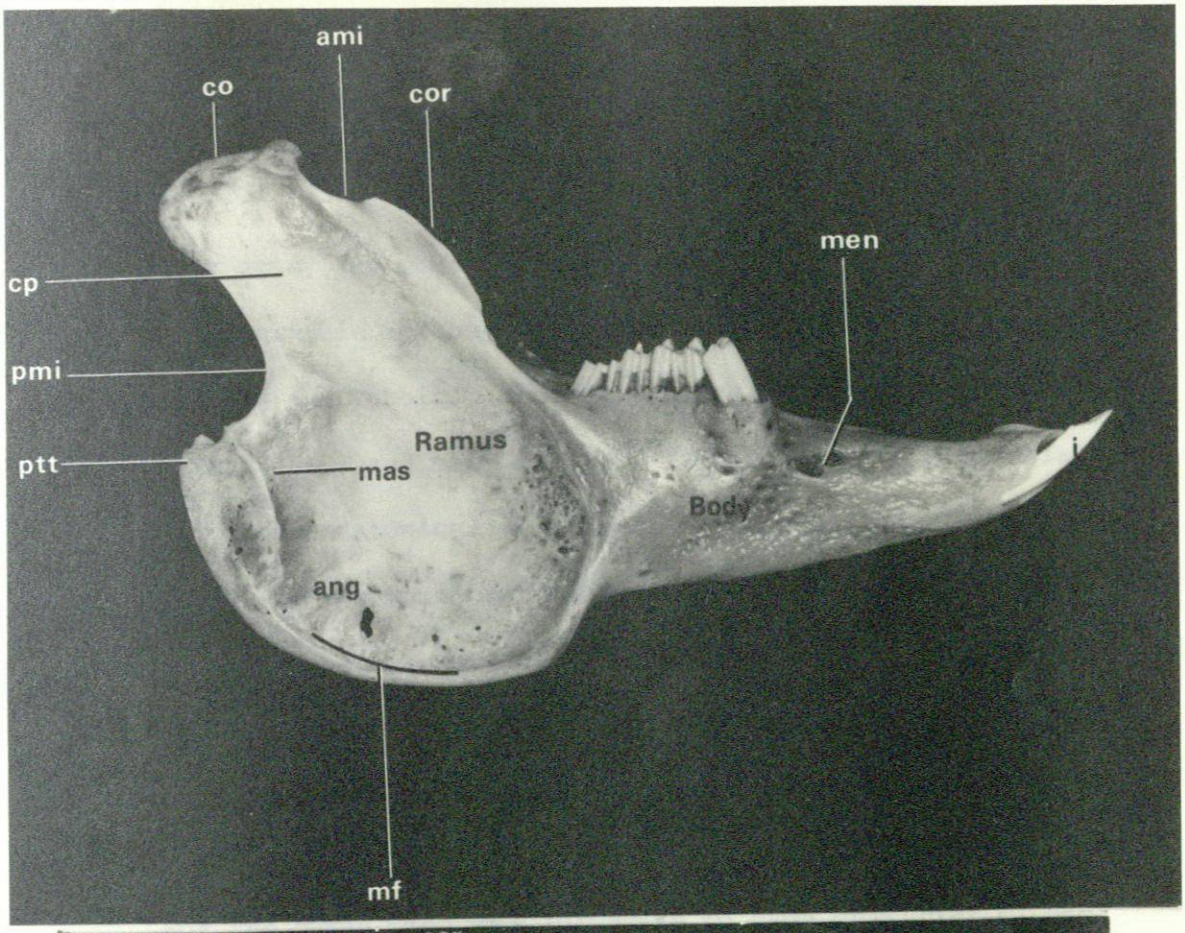
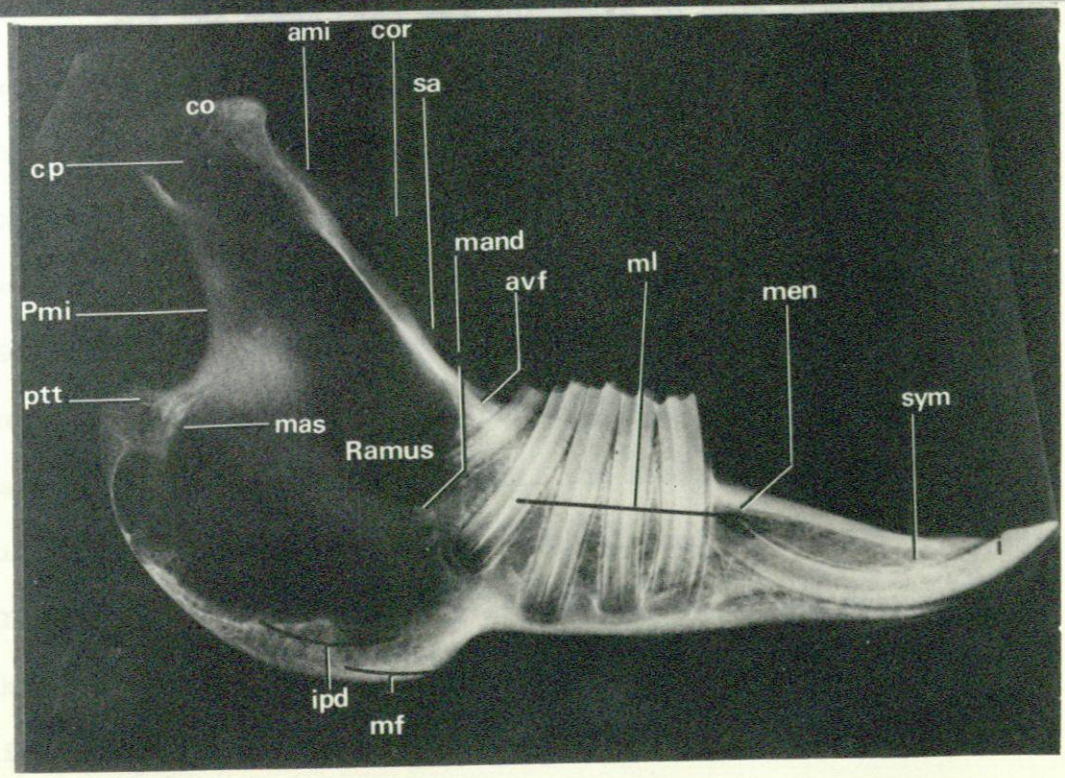

i
sym
men
p1
p2
m1
m2
m3
avf
sa
cor
mf
co
mas
ptt

PLATE XXIV.--Rabbit Mandible--Lateral

ami = anterior mandibular incisure
ang = angle
avf = anastomostic vein foramen
body = body
co = condyle
cor = coronoid process
cp = condyloid process
i = incisor
ipd = inferior pterygoid depression
mand = mandibular foramen
mas = masseteric tuberosity
men = mental foramen
mf = masseteric fossa
ml = mylohyoid line
pmi = posterior mandibular incisure
ptt = pterygoid tuberosity
ramus = ramus
sa = sulcus ascendens
sym = symphysis

PLATE XXV.--Rabbit Mandible--Cephalogram


ami
co
cor
men
cp
pmi
Ramus
ptt
mas
Body
i
ang
mf


ami
cor
sa
co
cp
mand
ml
avf
men
Pmi
ptt
sym
mas
Ramus
i
ipd
mf

DISCUSSION

This study was undertaken to compile a detailed atlas of verified radiographic anatomy for three common laboratory animals, rat, guinea pig and rabbit. The methodology paralleled that employed by Yen (1960) and many others. It involved the sequential labeling of known anatomical details on dried skulls to permit the identification of the more obvious shadows on cephalometric radiographs of the labeled preparations. Obviously, this is in theory a rather straight forward procedure. In practice, it soon became apparent that the rate-limiting step was the basic comparative osteology.

For the human, Yen was fortunate to have centuries of detailed human osteology to work with; however, in the present study major references for the species under investigation were few in number and often of questionable authority. Although there are a few anatomical texts for the rat and rabbit (Greene, 1935; Craigie, 1948), the osteology of the guinea pig and the supplemental gross anatomy of the rat and rabbit are available in only sketchy detail thus, it is necessary to cull the needed information, bit by bit, from a variety of animals, journals and theses (Tables I, II, III, IV). Given so diffuse a literature, it is not surprising that the various cephalometric analyses used in animals have very little in common.

Although it would clearly be beyond the scope of this discussion to attempt a detailed analysis of the comparative radiographic anatomy seen here, a few brief observations may be in order. Most cephalometric analyses employ some form of cranial base orientation, and, in humans, the center of sella turcica ("sella") is most often used for registration. Many workers, perhaps out of habit, have tried to use the same types of analyses in smaller animals. Unfortunately, as can be seen here, there is no bony sella turcica in either the rat or guinea pig. In the rat, the hypophysis is located adjacent to the spheno-occipital synchondrosis, and in the guinea pig it is situated in a slight depression immediately anterior to this synchondrosis. The rabbit, however, has a true sella located midway between the spheno-occipital and intersphenoidal synchondrosis

It is interesting to note that several investigators (Chiason, 1958; Moore and Spence, 1969)--probably by accident--have erroneously located sella.

In the three species studied here, two major synchondroses are located along the cranial base. For rats and rabbits, the spheno-occipital synchondrosis is easily visualized, whereas in the guinea pig it is obscured by the anterior margins of the tympanic bullae. The intersphenoidal synchondrosis, however, can be located in all three animals. Thus, from the standpoint of the lateral cephalogram, the cranial base of the rabbit can be visualized most completely.

However, with the exception of the location of the hypophyses,

the various structures of the rat cranial base--synchondrosis, ethmoid, vomer--are perhaps most clearly visible. Indeed, this clarity prompted Dubrul and Laskin (1961) to note that:

> The rat skull seems especially apropos for a beginning study of basic mamalian form because the metamerism of the primordial head is, at least, recalled by the symmetrical repetition of cartilage plates along the base. At any rate, this strategic array suggests a single device for making the skull grow long.

The cranial vaults, for each of the species studied, tended to have a qualitatively similar radiographic pattern. The bony organization of the vault--nasal, frontal, parietal, interparietal, occipital--and its associated sutures, were clearly visible on the lateral radiographs. Moreover, the cranial fossae and the location of the various parts of the brain (olfactory lobes, cerebral cortex, cerebellum) can be visualized clearly in all three.

The mandibulae can be seen clearly in radiographs and seem to differ mainly with respect to the relative size of the angular and coronoid processes (both well formed in the rat) and the type of dentition present. The mandibular canal is especially clear in radiographs of the rat (as opposed to the human) and, therefore, can be used as a meaningful landmark in view of recent work relating the mandibular nerve to facial growth (Ricketts, 1972; Moss, 1974). Moss (1974) states:

> The growth of the human mandible is not a haphazard event, but is intimately correlated with the location and growth of the inferior alveolar nerve.

Presumably, the present investigation, and others like it, will serve to provide a strong theoretical basis for the evolution

of a cephalometric technique which will be even more reliable and well characterized in the experimental laboratory than it is in the clinic. By definition, clinical applications are always anthropocentric; the human is the animal of interest and inherent technical limitations must be endured. However, many of the clinical requirements and anatomical restraints (usually, the lack of valid, reliable landmarks) that have influenced the development of clinical analyses need not restrict the vision of the craniofacial biologist. Rather, it should be possible to choose animal models that meet precisely the requirements of any given investigation. Indeed, modern biological laboratories have become home to a myriad of exotic species--each of which provide anatomical and physiological specializations appropriate to a given line of investigation (limulus eye, squid giant axon, etc.). It is assumed that within the animal kingdom there exists a range of variability that could prove of equivalent utility to the craniofacial biologist. The probable existence of newer, more appropriate animal models should constitute a powerful stimulus to the continued development of the line of investigation begun here--"comparative cephalometrics."

SUMMARY AND CONCLUSIONS

The details of human cephalometric radiographs have been characterized well enough to make the technique useful, both in the laboratory and the clinic. Of necessity, however, much experimentation must be done on non-human material. Unfortunately, the basic radiographic anatomy (for the most common laboratory animals) has not yet been investigated systematically.

The purpose of this investigation was to provide craniofacial biologists with a detailed atlas of verified roentgen-cephalometric structures and landmarks for several common laboratory animals.

The observations were obtained from a series of adult rats, guinea pigs, and rabbits. For each animal, standard lateral cephalograms were obtained of sagittally-sectioned dry skulls. Each half skull was labeled progressively with a radioopaque paste which served to outline ridges, processes, sutures, foramina, and fossae. For use as a "control," the unlabelled half skull was also radiographed, and then compared with the radiographs of the labeled skull section. In addition, dissection was conducted on fixed sections for each species.

A detailed atlas of verified lateral radiographic anatomy for each animal was then compiled utilizing the data gained from the dissection and labeled radiographs.

LITERATURE CITED

Alexais, H. 1899. Etude Anatomique Du Cobaye. Journal De L' Anatomie, 35: 333-381.

Asling, C. W., and Frank, H. R. 1963. Roentgen cephalometric studies on skull development in rats: Normal and hypophysectomized females. Am. J. Phys. Anthrop., 21: 527-543.

Ballard, O. T. 1937. The gross anatomy of the Cavia cobaya with a comparative study of another hystricomorph rodent, Erethizon dorsatus. Ph.D. Thesis, University of Kansas, Lawrence, Kansas.

Belhobek, J. H. 1974. The effect of unilateral progressive condylar compression on mandibular growth in the guinea pig. Unpublished M. S. Thesis, Case Western Reserve University, Cleveland, Ohio. 78 pp.

Broadbent, B. H. 1931. A new x-ray technique and its application to orthodontia. Angle Orthod., 1: 45-66.

Burr, E. G., and Mortimer, H. 1938. A cranial radiographic technique in the living rat. Radiology, 31: 162-169.

Chiason, R. B. 1958. Laboratory Anatomy of the White Rat. Dubuque, Iowa: William C. Brown Company, 48 pp.

Cleall, J. F., Jacobson, S. H., Chebib, F. S., and Berker, S. 1971. Growth of the craniofacial complex in the rat. Am. J. Orthod., 60: 368-381.

Cleall, J. F., Wilson, G. W., and Garnett, D. 1968. Normal craniofacial skeletal growth of the rat. Am. J. Phys. Anthrop., 29: 225-242.

Craigie, E. H. 1948. Bensleys Practical Anatomy of the Rabbit. Toronto: University of Toronto Press, 391 pp.

Craigie, E. H. 1966. A Laboratory Guide to the Anatomy of the Rabbit. Toronto: University of Toronto Press, pp. 21-27.

Debbane, E. F. 1958. A cephalometric and histologic study of the effect of orthodontic expansion of the midpalatal suture of the cat. Am. J. Orthod., 44: 187-219.

DuBrul, E. L., and Laskin, D. M. 1961. Preadaptive potentialities of the mammalian skull: An experiment in growth and form. Am. J. Anat., 109: 117-132.

Erickson, L. C., and Ogilvie, A. L. 1958. Aspects of growth in the cranium, mandible, and teeth of the rabbit as revealed through the use of alizarin and metallic implants. Angle Orthod., 28: 47-56.

Etter, L. E. 1955. Atlas of Roentgen Anatomy of the Skull. Springfield, Illinois: Charles Thomas. 215 pp.

Farris, E. J., and Griffith, J. Q. 1942. The Rat in Laboratory Investigations. Philadelphia: J. B. Lippincott. 488 pp.

Ford, E. H. R., and Horn, G. 1959. Some problems in the evaluation of differential growth in the rat's skull. Growth, 23: 191-204.

Fuller, D. S. 1974. An investigation of growth of the mandibular condyle following condylotomy in the guinea pig. Unpublished M. S. Thesis, Case Western Reserve University, Cleveland, Ohio. 54 pp.

Gange, R. J. 1973. The septopremaxillary ligament and nasomaxillary growth in the albino rat. Unpublished M. S. Thesis, Case Western Reserve University, Cleveland, Ohio. 65 pp.

Gans, B. J., and Sarnat, B. G. 1951. Sutural facial growth of the Macaca rhesus monkey: A gross and serial roentgenographic study by means of metallic implants. Am. J. Orthod., 37: 827-841.

Gardner, A. F., Dasler, W., and Weinmann, J. P. 1958. Masticatory apparatus of albino rats in experimental lathyrism. J. Dent. Res., 37: 492-515.

Greene, E. 1935. Anatomy of the rat. Trans. Am. Phil. Soc., 27: new series. 370 pp.

Hatton, M. E., and Grainger, R. M. 1958. Reliability of measurements from cephalograms at the Burlington Orthodontic Research Center. J. Dent. Res., 37: 853-859.

Hoffman, D. R. and Tade, W. H. 1972. Improved technique for sectioning the inferior alveolar nerve in rats. J. Dent. Res., 51(2): 668.

Hofrath, H. 1931. Die bedeutung der röentgenfern und abstandsaufnahue für die diagnosok der kieferanomalien. Fortschr. der Orthod., 1: 232-242.

Hong, Y. C., Yen, P. K. J., and Shaw, J. H. 1968. An analysis of the growth of the cranial vault in rabbits by vital staining with lead acetate. Calc. Tiss. Res., 2: 271-285.

Horowitz, S. L., and Shapiro, H. H. 1951. Modifications of mandibular architecture following removal of temporalis muscle in the rat. J. Dent. Res., 30: 276-280.

Horowitz, S. L., and Shapiro, H. H. 1955. Modification of skull and jaw architecture following removal of the masseter muscle in the rat. Am. J. Phys. Anthrop., 13: 301-308.

Hoyte, D. A. N. 1967. The Modes of Growth of the Neurocranium: The Growth of the Sphenoid Bone in Animals. University of Michigan Conference on Craniofacial Growth, Ann Arbor, Michigan. Great Britian: Pergamon Press. pp. 77-105.

Hoyte, D. A. N. 1968. Alizarin red in the study of the apposition and resorption of bone. Am. J. Phys. Anthrop., 29: 157-178.

Hoyte, D. A. N. 1971. Mechanisms of growth in the cranial vault and base. J. Dent. Res., 50(6 Suppl.): 1447-1461.

Huelke, D. F., and Castelli, W. A. 1965. The blood supply of the rat mandible. Anat. Rec., 153: 335-342.

Isotupa, K., Koski, K., and Mäkinen, L. 1965. Changing architecture of growing cranial bones at sutures as revealed by vital staining with alizarin reds in the rabbit. Am. J. Phys. Anthrop., 23: 19-22.

Jarabak, J. R. 1942. Animal cephalometry. Angle Orthod., 12: 87-93.

Krogman, W. M., and Sassouni, V. 1957. A syllabus in roentgenographic cephalometry. Phila. Center for Res. in Child Growth, Philadelphia, pp. 63-84.

Linden, van der, F. P. G. M. 1971. A study of roentgenocephalometric bony landmarks. Am. J. Orthod., 59: 111-125.

Marshall, D. 1970. Interpretation of the lateral skull radiograph. Assembly of Disarticulated Bones. Dental Radiography and Photography, 43: 71-82.

Martin, H. N., and Moale, W. A. 1895. Handbook of Vertebrate Dissection: How to Dissect a Rodent. New York: MacMillan and Company, pp. 168-209.

Massler, M., and Schour, I. 1951. The growth pattern of the cranial vault in the albino rat as measured by vital staining with alizarine red "S." Anat. Rec., 110: 83-101.

McLaughlin, C. A. 1970. Laboratory Anatomy of the Rabbit. Dubuque, Iowa: William C. Brown Company, pp. 1-21.

Miller, P. A., Savara, B. S., and Singh, I. J. 1966. Analysis of errors in cephalometric measurement of three dimensional distances on the maxilla. Angle Orthod., 36: 169-175.

Mohammed, C. I. 1957. Growth pattern of the rat maxilla from 10 days insemination age to 30 days after birth. Am. J. Anat., 100: 115-165.

Moore, W. J. 1966. Skull growth in the albino rat (Rattus norvegicus). J. Zool., 149: 137-144.

Moore, W. J., and Spence, T. F. 1969. Age changes in the cranial base of the rabbit (Oryctolagus cuniculus). Anat. Rec., 165: 355-362.

Mortimer, H. 1937. Pituitary and associated hormone factors in cranial growth and differentiation in the white rat: A roentgenological study. Radiology, 28: 5-39.

Moss, M. L. 1954. Growth of the calvaria in the rat: The determination of osseous morphology. Am. J. Anat., 94(3): 333-362.

Moss, M. L. 1958. Fusion of the frontal suture in the rat. Am. J. Anat., 102: 141-165.

Moss, M. L. 1960. Inhibition and stimulation of sutural fusion in the rat calvaria. Anat. Rec., 136: 457-467.

Moss, M. L., and Baer, M. J. 1956. Differential growth of the rat skull. Growth, 20: 107-120.

Moss, M. L., Moss-Salentijn, L., and Ostreicher, H. P. 1974. The logarithmic properties of active and passive mandibular growth. Am. J. Orthod., 66: 645-664.

Ossian, C. R. 1970. Preparation of disarticulated skeletons using enzyme-based laundry "pre-soakers." Ichtyol Notes, 1: 199-200.

Pitel, M. 1947. Some anatomical and physiological aspects of the guinea pig. Unpublished M. S. Thesis, Western Reserve University, Cleveland, Ohio. 108 pp.

Pratt, L. W. 1943. Experimental masseterectomy in the laboratory rat. J. Mammal., 24: 204-211.

Rayne, J., and Crawford, G. N. C. 1972. The relationship between fibre length, muscle excursion and jaw movements in the rat. Arch. Oral Biol., 17: 859-872.

Retief, D. H., and Dreyer, C. J. 1969. Sectioning of the inferior dental nerve in rats. J. Dent. Res., 48: 969.

Ricketts, R. M. 1972. A principle of arcial growth of the mandible. Angle Orthod., 42: 368-386.

Robinson, I. B., and Sarnat, B. G. 1955. Growth pattern of the pig mandible. A serial roentgenographic study using metallic implants. Am. J. Anat., 96: 37-64.

Rönning, O., and Isotupa, K. 1973. Changes in the dentition of the guinea pig following partial section of the inferior alveolar nerve. Arch. Oral Biol., 18: 1059-1062.

Sarnat, B. G. 1970. The face and jaws after surgical experimentation with the septovomeral region in growing and adult rabbits. Acta Otolaryng., Suppl. 268: 3-30.

Sarnat, B. G., and Shanedling, P. D. 1965. Postnatal growth of the orbit and upper face in rabbits after exenteration of the orbit. Arch. Ophthal., 73: 829-837.

Sarnat, B. G., and Wexler, M. R. 1966. Growth of the face and jaws after resection of the septal cartilage in the rabbit. Am. J. Anat., 118: 755-768.

Sarnat, B. G., and Wexler, M. R. 1967a. Rabbit snout growth after resection of central linear segments of nasal septal cartilage. Acta. Otolaryng., 63: 467-478.

Sarnat, B. G., and Wexler, M. R. 1967b. The snout after resection of nasal septum in adult rabbits. Arch. Otolaryng., 86: 463-466.

Sarnat, B. G., and Wexler, M. R. 1968. Postnatal growth of the nose and face after resection of septal cartilage in the rabbit. Oral Surg., Oral Med., and Oral Path., 26: 712-727.

Sarnat, B. G., and Wexler, M. R. 1969. Longitudinal development of upper facial deformity after septal resection in growing rabbits. Brit. J. Plast. Surg., 22: 313-323.

Savara, B. S., Tracy, W. E., and Miller, P. A. 1966. Analysis of errors in cephalometric measurements of three dimensional distances on the human mandible. Arch. Oral Biol., 11: 209-217.

Sawin, P. B., Ranlett, M., and Crary, D. D. 1959. Morphogenetic studies of the rabbit: XXV. The spheno-occipital synchondrosis of the dachs (chonorodystrophy) rabbit. Am. J. Anat., 105: 257-280.

Schumacher, Von G. H., and Rehmer, H. 1962. Uber einige unterschiede an kauapparat bei bagomorphen und rodentia. Anat. Anz., 111: 103-122.

Selman, A. J., and Sarnat, B. G. 1953. A headholder for serial roentgenography of the rabbit skull. Anat. Rec., 115: 627-634.

Selman, A. J., and Sarnat, B. G. 1955. Sutural bone growth of the rabbit snout: A gross serial roentgenographic study by means of metallic implants. Am. J. Anat., 97: 395-408.

Selman, A. J., and Sarnat, B. G. 1957. Growth of the rabbit snout after extirpation of the frontonasal suture: A gross and serial roentgenographic study by means of metallic implants. Am. J. Anat., 101: 273-294.

Simmons, M. L., and Brick, J. O. 1970. The Laboratory Mouse: Selection and Management. Englewood Cliffs, New Jersey: Prentice-Hall Biological Technical Series. 184 pp.

Simpson, C. D. 1966. Experimental mandibular dysplasia. Angle Orthod., 36: 224-235.

Spence, J. M. 1940. Method of studying the skull development of the living rat by serial cephalometric roentgenograms. Angle Orthod., 10: 127-139.

Stenström, S. J., and Thilander, B. L. 1967. Facial skeleton growth after bone grafting to surgically created premaxillomaxillary suture defects: An experimental study on the guinea pig. Plast. Reconstruct. Surg., 40: 1-12.

Stenström, S. J., and Thilander, B. L. 1970. Effects of nasal septal cartilage resections on young guinea pigs. Plast. Reconstruct. Surg., 45: 160-170.

Strong, R. M. 1925. The order, time and rate of ossification of albino rat (Mus Norvegicus albinus) skeleton. Am. J. Anat., 36: 313-355.

Vilmann, H. 1968. The growth of the parietal bone in the albino rat studied by roentgenocephalometry and vital staining. Arch. Oral Biol., 13: 887-903.

Vilmann, H. 1969. The growth of the cranial base in the albino rat as revealed by roentgenocephalometry. J. Zool., 159: 283-291.

Vilmann, H. 1972. The growth of the cranial vault in the albino rat. Arch. Oral Biol., 17: 399-414.

Vinogradov, B. S., and Argiropulo, A. I. 1968. Fauna of the U.S.S.R. Jerusalem: Israel Program for Scientific Translations. 230 pp.

Wexler, M. R., and Sarnat, B. G. 1961. Rabbit snout growth: Effect of injury to the septovomeral region. Arch. Otolaryng., 74: 305-313.

Wexler, M. R., and Sarnat, B. G. 1965. Rabbit snout growth after dislocation of nasal septum. Arch. Otolaryng., 81: 68-71.

Whitehouse, R. H., and Grove, A. J. 1947. The Dissection of the Rabbit. London: University Tutorial Press Ltd., pp. 28-32.

Wragg, L. E., Steinvorth, M., and Warpeha, R. 1970. Facial growth accomodating secondary palate closure in rat and man. Arch. Oral Biol., 15: 705-719.

Wright, H. V., Kjaer, I., and Asling, C. W. 1966. Roentgen cephalometric studies on skull development in rats. II. Normal and hypophysectomized males. Am. J. Phys. Anthrop., 25: 103-118.

Yen, P. K. J. 1960. Identification of landmarks in cephalometric radiographs. Angle Orthod., 30: 35-41.

Young, R. W. 1959. The influence of cranial contents on postnatal growth of the skull in the rat. Am. J. Anat., 105: 383-415.

APPENDIX I

Rat Skull--Dorsal and Ventral Anatomy

PLATE XXVI--Dorsal

PLATE XXVII--Ventral

PLATE XXVI.--Rat Skull--Dorsal

Fr = Frontal
Ip = Interparietal
Jp = Jugal process
La = Lacrimal
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Na = Nasal
Occ = Occipital
Par = Parietal
Prefr = frontal process of Premaxillary
Szy = zygomatic process of Squamosal
als = anterior lambdoidal suture
cs = coronal suture
eop = external occipital protuberance
fns = frontonasal suture
if = infraorbital fissure
ifs = interfrontal suture
ins = internasal suture
lc = lambdoidal crest
nlc = naso-lacrimal canal
nps = naso-premaxillary suture
oc = occipital condyle
pls = posterior lambdoidal suture
pp = paramastoid process
psr = parasagittal ridge
pth = post tympanic hook
ss = sagittal suture

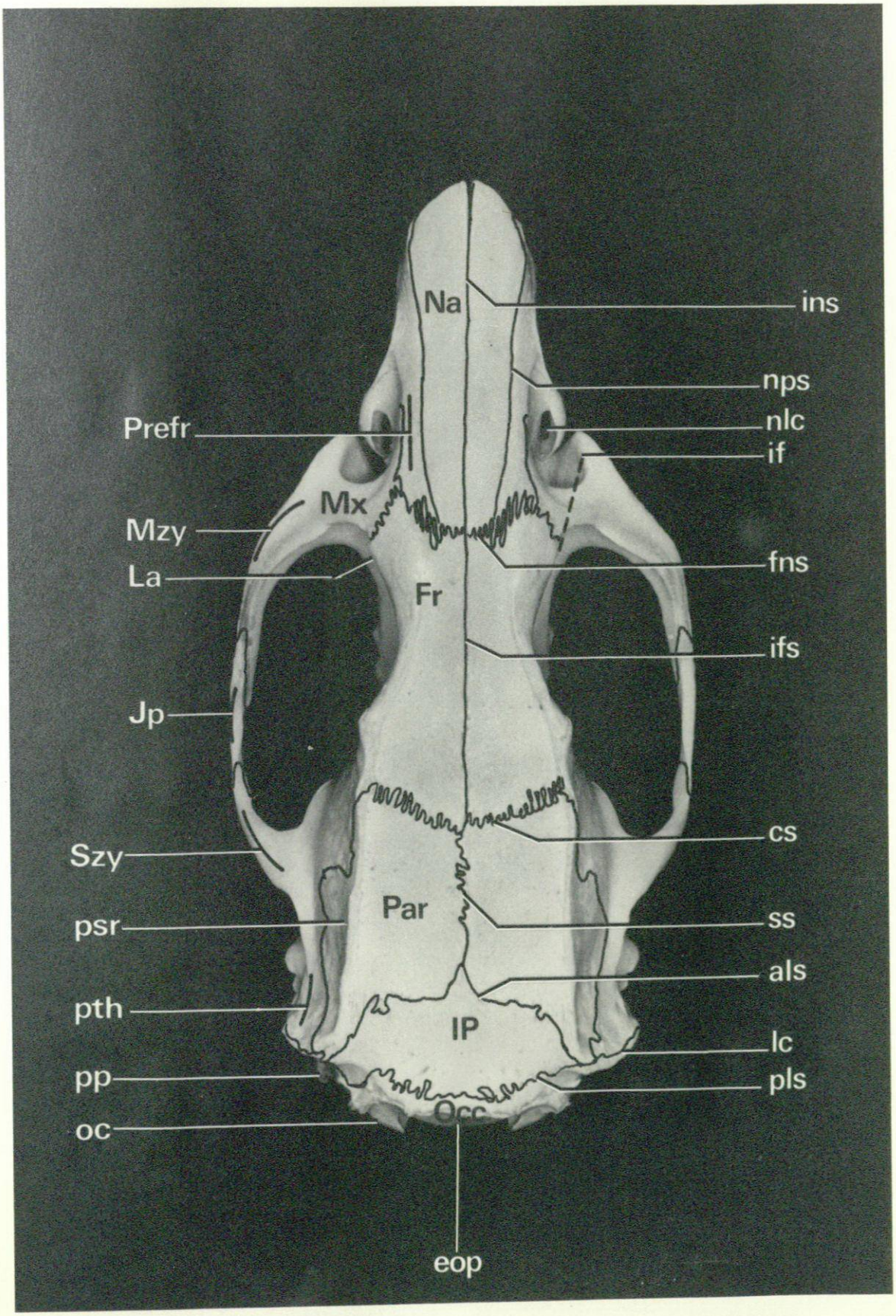
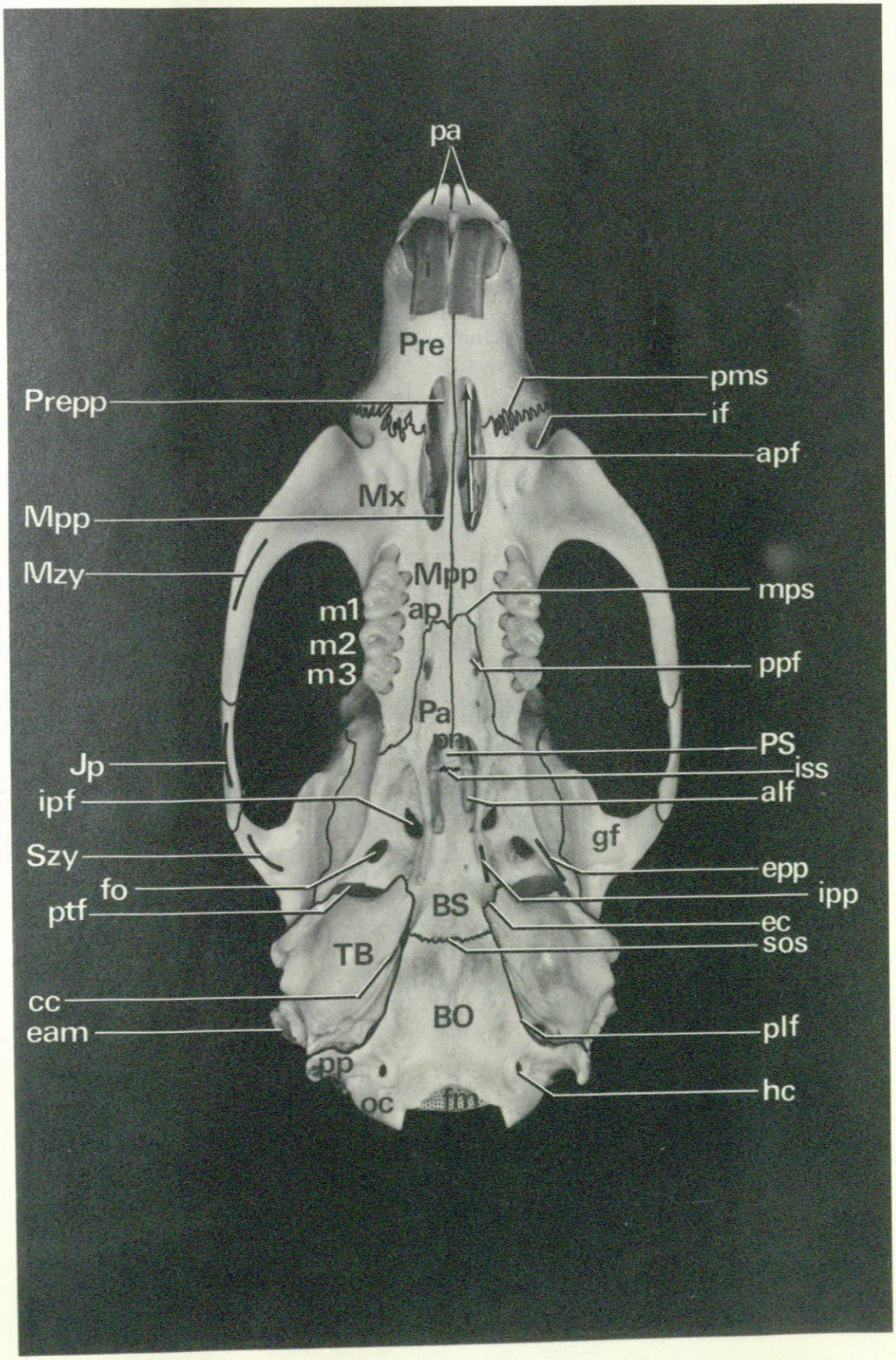

Na
ins
nps
Prefr
nlc
if
Mx
Mzy
La
fns
Fr
ifs
Jp
cs
Szy
Par
psr
ss
als
pth
IP
lc
pp
pls
Occ
oc
eop

PLATE XXVII.--Rat Skull--Ventral

BO = Basioccipital
BS = Basisphenoid
Jp = Jugal process
Mpp = palatine process of Maxillary
Mx = Maxillary
Mzy = zygomatic process of Maxilla
Pa = Palatine
Pre = Premaxillary
Prepp = palatine process of Premaxillary
PS = Presphenoid
Szy = zygomatic process of Squamosal
TB = Tympanic bulla
alf = anterior lacerated foramen
ap = alveolar process
apf = anterior palatine foramen
cc = carotid canal
eam = external auditory meatus
ec = eustachian canal
epp = external pterygoid plate
fm = foramen magnum
fo = foramen ovale
gf = glenoid fossa
hc = hypoglossal canal
i = incisor
if = infraorbital fissure
ipf = interpterygoid foramen
ipp = internal pterygoid plate
iss = intersphenoidal synchondrosis
m1, m2, m3 = molars
mps = maxillo-palatine suture
oc = occipital condyle
pa = piriform aperature
plf = posterior lacerated foramen
pms = premaxillo-maxillary suture
pn = posterior nares
pp = paramastoid process
ppf = posterior palatine process
ptf = petrotympanic fissure
sos = sphenoocipital synchondrosis


pa
Pre
Prepp
pms
if
apf
Mx
Mpp
Mzy
Mpp
ap
mps
m1
m2
m3
ppf
Pa
pp
PS
iss
Jp
ipf
alf
gf
Szy
epp
fo
ipp
ptf
BS
ec
sos
TB
cc
BO
eam
plf
pp
oc
hc

APPENDIX II

Guinea Pig Skull--Dorsal and Ventral Anatomy

PLATE XXVIII--Dorsal

PLATE XXIX--Ventral

PLATE XXVIII.--Guinea Pig Skull--Dorsal

Fr = Frontal
Ip = Interparietal
Jp = Jugal process
La = Lacrimal
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Na = Nasal
Par = Parietal
Prefr = frontal process of Premaxillary
Sq = Squamosal
Szy = zygomatic process of Squamosal
als = anterior lambdoidal suture
cs = coronal suture
eam = external auditory meatus
eop = external occipital protuberance
fns = frontonasal suture
ifs = interfrontal suture
inf = infraorbital foramen
ins = internasal suture
lc = lambdoidal crest
ln = lacrimal notch
obc = orbital crest
pa = piriform aperature
pls = posterior lambdoidal suture
pth = post tympanic hook
sc = sagittal crest
sqs = squamosal suture

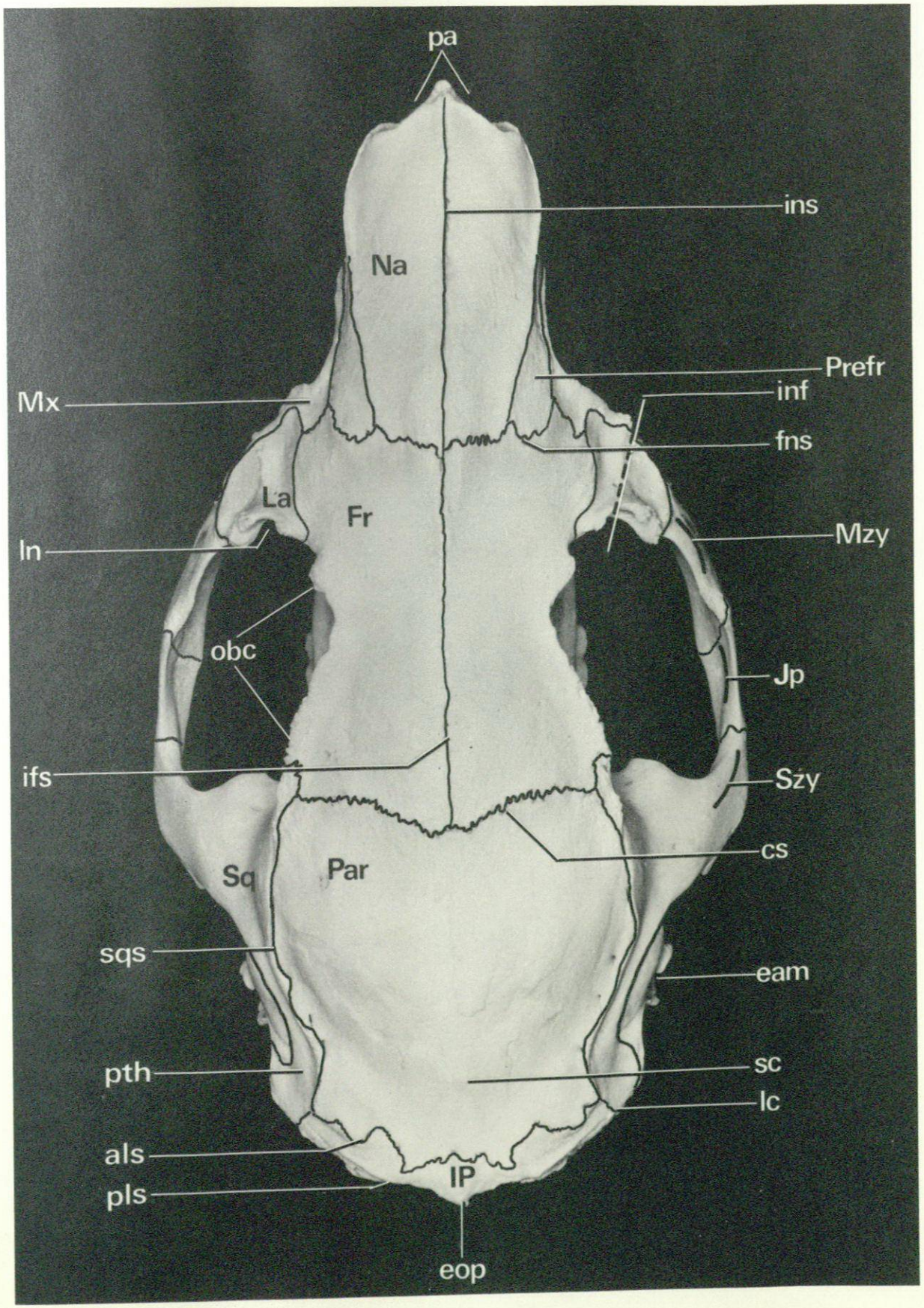
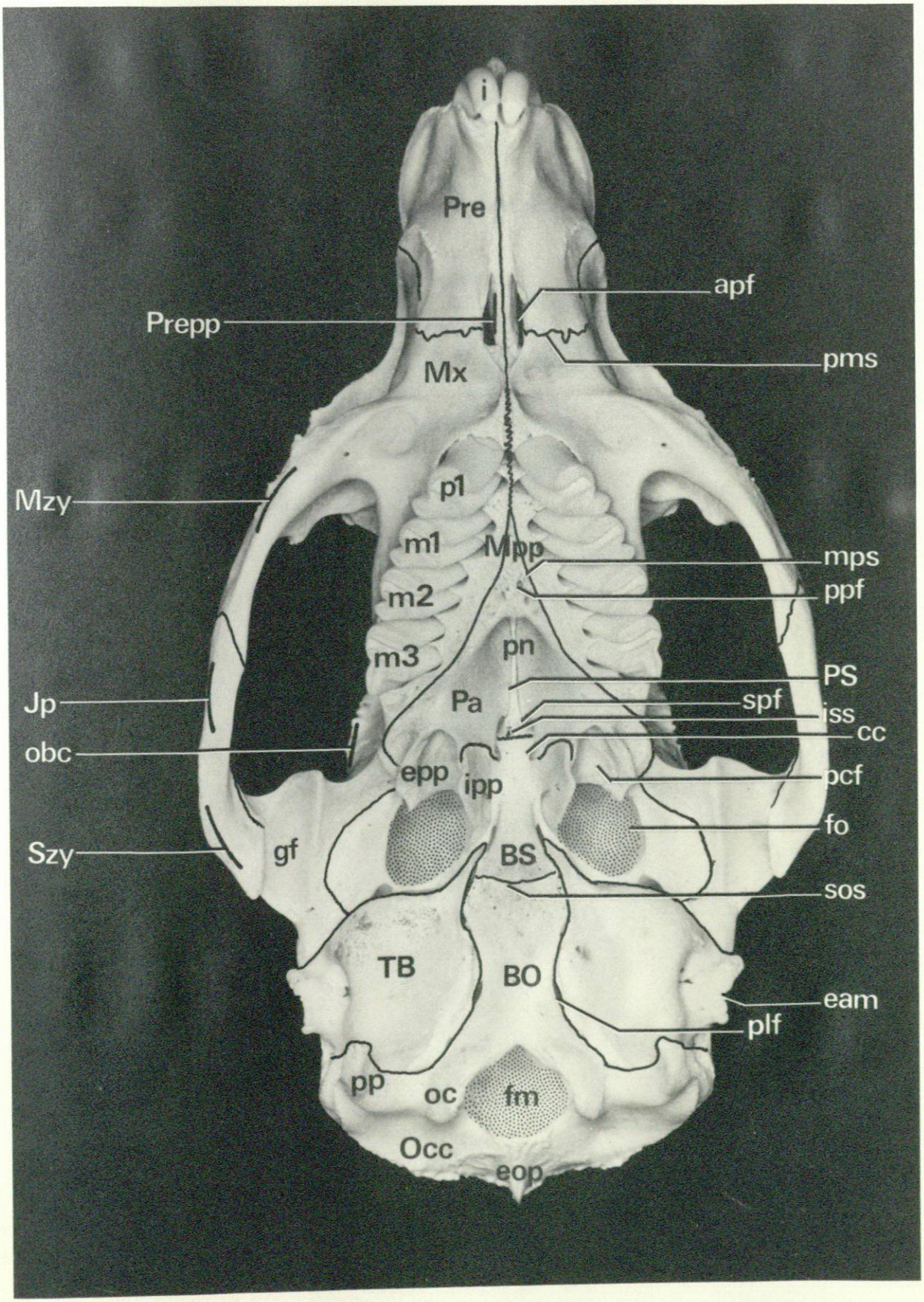

pa
ins
Na
Prefr
Mx
inf
fns
La
Fr
ln
Mzy
obc
Jp
ifs
Szy
cs
Sq
Par
sqs
eam
pth
sc
lc
als
IP
pls
eop

PLATE XXIX.--Guinea Pig Skull--Ventral

BO = Basioccipital
BS = Basisphenoid
Jp = Jugal process
Mpp = palatine process of Maxillary
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Occ = Occipital
Pal = Palatine
Pre = Premaxillary
Prepp = palatine process of Premaxillary
PS = Presphenoid
Szy = zygomatic process of Squamosal
TB = Tympanic bulla
apf = anterior palatine foramen
cc = carotid canal
eam = external auditory meatus
eop = external occipital protuberance
epp = external pterygoid plate
fm = foramen magnum
fo = foramen ovale
gf = glenoid fossa
i = incisor
ipp = internal pterygoid plate
iss = intersphenoidal synchondrosis
m1, m2, m3 = molars
mps = maxillo-palatine suture
obc = orbital crest
oc = occipital condyle
pl = premolars
plf = posterior lacerated foramen
pms = premaxillo-maxillary suture
pn = posterior nares
pp = paramastoid process
ppf = posterior palatine foramen
ptf = petrotympanic fissure
sos = sphenooccipital synchondrosis
spf = sphenopalatine foramen


i
Pre
apf
Prepp
pms
Mx
p1
Mzy
m1
Mpp
mps
m2
ppf
m3
pn
PS
Jp
Pa
spf
iss
cc
obc
epp
ipp
pcf
fo
Szy
gf
BS
sos
TB
BO
eam
plf
pp
oc
fm
Occ
eop

APPENDIX III

Rabbit Skull--Dorsal and Ventral Anatomy

PLATE XXX--Dorsal

PLATE XXXI--Ventral

PLATE XXX.--Rabbit Skull--Dorsal

Fr = Frontal
Ip = Interparietal
Jp = Jugal process
La = Lacrimal
Na = Nasal
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Par = Parietal
Prefr = frontal process of Pre-maxillary
SO = Supraoccipital
Sq = Squamosal
Szy = zygomatic process of Squamosal
als = anterior lambdoidal suture
asp = anterior supraorbital process of frontal
cs = coronal suture
eam = external auditory meatus
eop = external occipital protuberance
fns = frontonasal suture
fs = frontal spine
ifs = interfrontal suture
ins = internasal suture
lca = lacrimal canal
mp = mastoid process
nps = naso-premaxillary suture
pa = piriform aperature
pls = posterior lambdoidal suture
psp = posterior supraorbital process of frontal
sm = spina masseterica
sor = supraorbital ridge
sqp = squamosal process of squamosal
ss = sagittal suture

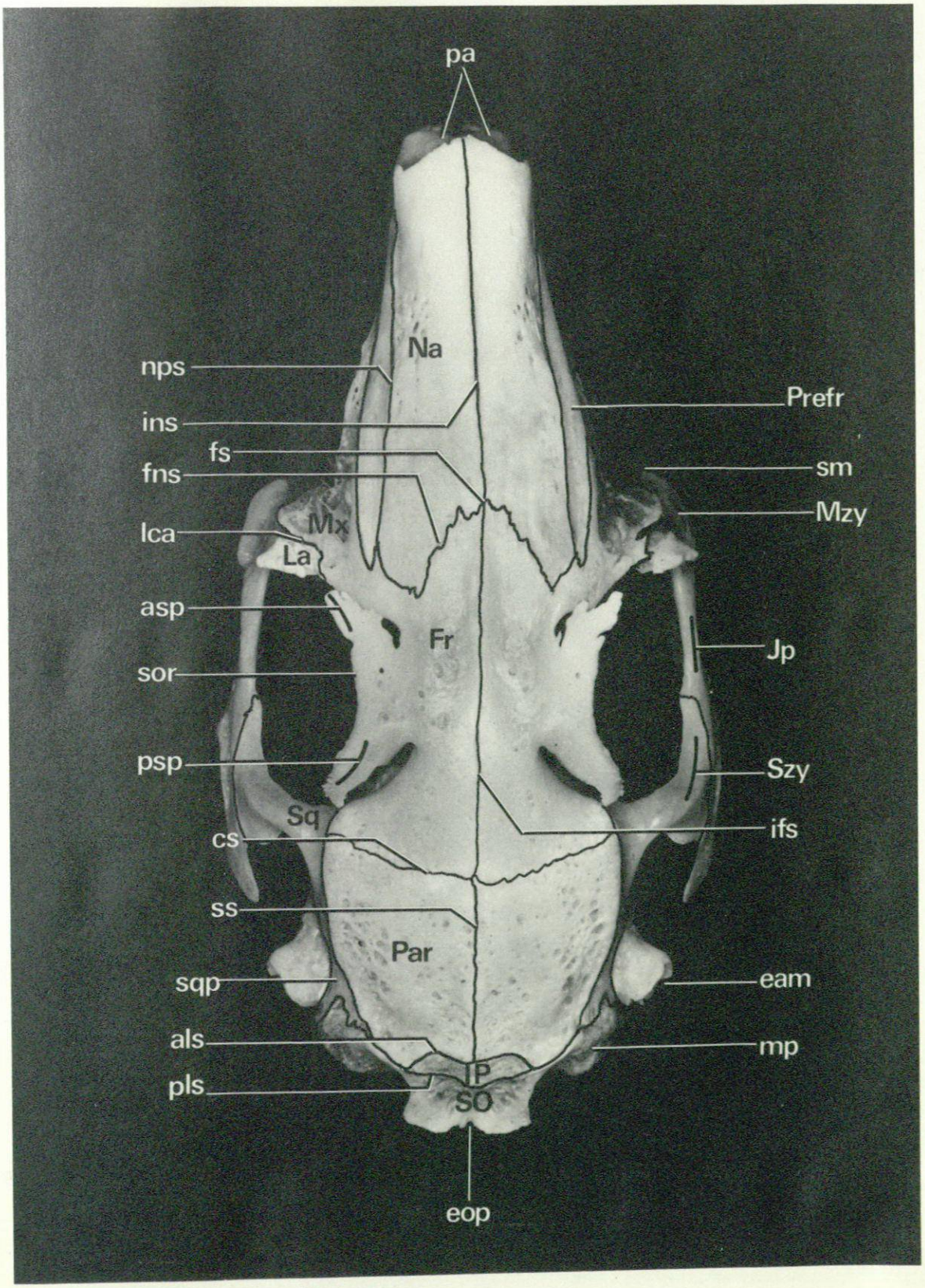
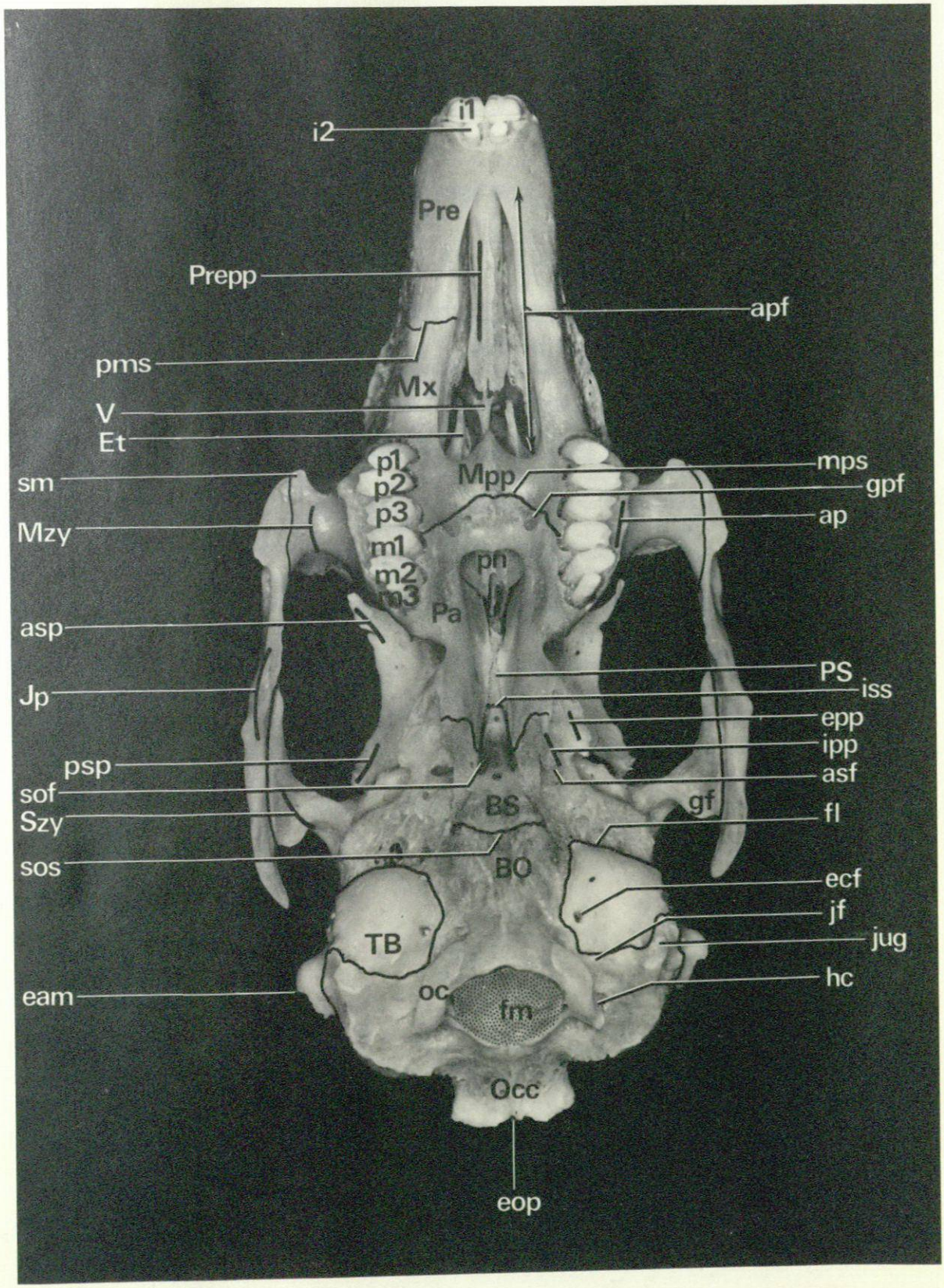

pa
Na
nps
ins
fs
fns
lca
Mx
La
asp
Fr
sor
psp
Sq
cs
ss
Par
sqp
als
pls
IP
SO
eop
Prefr
sm
Mzy
Jp
Szy
ifs
eam
mp

PLATE XXXI.--Rabbit Skull--Ventral

BO = Basioccipital
BS = Basisphenoid
Et = Ethmoturbinates
Jp = Jugal process
Mpp = palatine process of Maxillary
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Occ = Occipital
Pa = Palatine
Pre = Premaxillary
Prepp = palatine process of Premaxillary
PS = Presphenoid
Szy = zygomatic process of Squamosal
TB = Tympanic bulla
V = Vomer
ap = alveolar process
apf = anterior palatine foramen
asf = anterior sphenoidal foramen
asp = anterior supraorbital process of frontal
eam = external auditory meatus
ecf = external carotid foramen
eop = external occipital protuberance
epp = external pterygoid plate
fl = foramen lacerum
fm = foramen magnum
gf = glenoid fossa
gpf = greater palatine foramen
hc = hypoglossal canal
i1, i2 = incisor
ipp = internal pterygoid plate
iss = intersphenoidal synchondrosis
jf = jugular foramen
jug = jugular process
m1, m2, m3 = molars
mps = maxillo-palatine suture
oc = occipital condyle
p1, p2, p3 = premolars
pms = premaxillo-maxillary suture
pn = posterior nares
psp = posterior supraorbital process of frontal
sm = spina masseterica
sof = superior orbital fissure
sos = sphenoocipital synchondrosis


i1
i2
Pre
Prepp
apf
pms
Mx
V
Et
p1
p2
p3
m1
m2
m3
Mpp
mps
gpf
ap
sm
Mzy
pn
Pa
asp
PS
iss
Jp
epp
ipp
asf
psp
sof
gf
fl
Szy
BS
sos
BO
ecf
jf
jug
TB
hc
eam
oc
fm
Occ
eop

APPENDIX IV

TAXA--RAT, GUINEA PIG, RABBIT

	Rat	Guinea Pig	Rabbit
Phylum	Chordata	Chordata	Chordata
Subphylum	Vertebrata	Vertebrata	Vertebrata
Class	Mammalia	Mammalia	Mammalia
Order	Rodentia	Rodentia	Lagomorphia
Family	Muridae	Cavidae	Leporidae
Genus	*Rattus*	*Cavia*	*Oryctolagus*
Species	*norvegicus*	*porcellus*	*cuniculus*

APPENDIX V

DENTITION--RAT, GUINEA PIG, RABBIT

Animal	Incisors	Cuspids	Premolars	Molars
Rat				
Maxillary	1	0	0	3
Mandibular	1	0	0	3
Guinea Pig				
Maxillary	1	0	1	3
Mandibular	1	0	1	3
Rabbit				
Maxillary	2	0	3	3
Mandibular	1	0	2	3

APPENDIX VI

LIST OF ABBREVIATIONS

Skulls--Lateral and Sagittal Structures

Cephalograms--Lateral and Sagittal Structures

AS = Alisphenoid
BO = Basioccipital
BS = Basisphenoid
Ecr = cribiform process of Ethmoid
Et = Ethmoturbinates
Emp = median plate of Ethmoid
Fr = Frontal
Ip = Interparietal
Jp = Jugal process
La = Lacrimal
Mpp = palatine process of Maxillary
Ms = Mastoid portion of Petromastoid
Mt = Maxilloturbinate
Mx = Maxillary
Mzy = zygomatic process of Maxillary
Na = Nasal
Nt = Nasoturbinates
Occ = Occipital
OS = Orbitosphenoid
Pa = Palatine
Par = Parietal
Pc = Periotic capsule
Pre = Premaxillary
Prefr = frontal process of Premaxillary
PS = Presphenoid
Sq = Squamosal
Szy = zygomatic process of Squamosal
T = Turbinate
TB = Tympanic bulla
V = Vomer

ac = alisphenoid canal
acf = anterior cranial fossa
aef = anterior ethmoidal foramen
alf = anterior lacerated foramen
als = anterior lambdoidal suture
ap = alveolar process
apf = anterior palatine foramen
asp = anterior supraorbital process of frontal
ba = basion
cs = coronal suture
eam = external auditory meatus
eoc = external occipital crest
eop = external occipital protuberance
epp = external pterygoid plate
fc = facial canal
fm = foramen magnum
fns = frontonasal suture
fo = foramen ovale
gf = glenoid fossa
hc = hypoglossal canal
hf = hypophyseal fossa
hp = hard palate
i1, i2 = incisor
iam = internal auditory meatus
inf = infraorbital foramen
ipf = interpterygoid foramen
ipp = internal pterygoid plate
iss = intersphenoidal synchondrosis
jug = jugular process
lc = lambdoidal crest
lca = lacrimal canal
m1, m2, m3 = molars
mcf = middle cranial fossa
mlf = middle lacerated foramen
mp = mastoid process
mps = maxillo-palatine suture
na = nasion

APPENDIX VI continued

nc = nasal canal
ns = nasal septum
obf = orbital fissure
oc = occipital condyle
of = optic foramen
opi = opisthion
pa = piriform aperature
pcf = posterior cranial fossa
pf = postglenoid foramen
pff = parafloccular fossa
pls = posterior lambdoidal suture
pms = premaxillo-maxillary suture
pn = posterior nares
pp = paramastoid process
psp = posterior supraorbital process of frontal
psr = parasagittal ridge
pth = post tympanic hook
rh = rhinal ridge
sm = spina masseterica
smf = stylomastoid foramen
soc = supraorbital crest
sof = superior orbital fissure
sos = sphenooccipital synchondrosis
spf = sphenopalatine foramen
sqp = squamosal process of squamosal
tc = tentorium cerebelli

GENERAL BOOKBINDING CO.
299CS 104 T
75 0 5 6291
QUALITY CONTROL MARK

CLEVELAND HEALTH SCIENCES LIBRARY
HEALTH CENTER LIBRARY

For Reference

Not to be taken from this room

Health Center Library



Cleveland Health Sciences Library of
Case Western Reserve University and
The Cleveland Medical Library Association.

CWRU LIBRARY SYSTEMS



3 9156 00575097 6