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[PLATES I-VI.]

JUNE 20, 1905

THE BLOOD-VASCULAR SYSTEM OF THE LOR-
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BY

WILLIAM F. ALLEN.

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SECTION I. INTRODUCTORY.

I. INTRODUCTION.

THE blood-vascular system of fishes is no new subject. It has been carefully worked out for many groups. We have the memoirs of Müller on *Myxine*, T. J. Parker on *Mustelus*, Hyrtl on the roaches, McKenzie on *Ameiurus*, Vogt on *Salmo*, Emery on *Fierasfer*, Cuvier and Valenciennes on *Perca*, and the general account found in Stannius' Anatomy. The object of this paper is to give a fairly complete account of the vascular system of *Ophiodon elongatus* (blue cod); and to make some comparisons with other members of the suborder LORICATI, the mailed-cheeked fishes. In a later paper I hope to go more into detail with the peripheral endings of the vessels in the organs of the viscera and those of special sense, as well as to take up the lymphatics.

This group of fishes is distinguished by the extension of the third suborbital bone across the cheek as a stay to or toward the preopercle. In view of the wide variation in this group, Dr. Gill says (45)¹ that it is not a natural division. He, however, divides this suborder into 8 different families, placing the Scorpænidæ (the rock fishes), as the most generalized, on account of their resemblance in form to the Serranidæ and Sparidæ; and the Cottidæ (the sculpins) are placed as the most specialized. Between these extremes come the family Hexagrammidæ, placed nearer the Scorpænidæ than the Cottidæ. There are, however, many points of resemblance to the Cottidæ to be found in their osteology, visceral organs, nervous and vascular systems.

The subfamilies *Hexagramminæ*, *Ophiodontinæ*, *Zaniolepidinæ*, and *Oxylebiinæ*, given by Jordan and Evermann (45, p. 1864), are very strongly marked. *Ophiodon* and probably *Zaniolepis* are about as closely related to *Scorpænichthys*, a sculpin, as they are to *Hexagrammos*, and should be regarded as types of distinct families.

The following species of fishes were studied.

¹ All figures in brackets refer to bibliography at the end of the paper.

Family SCORPÆNIDÆ.

Sebastodes flavidus Ayres, yellow-tail rockcod; *S. melanops* Girard; *S. mystinus* J. & G., black fish; *S. auriculatus* Girard, brown rockcod; *S. carnatus* J. & G., flesh-colored rockcod, and *S. nebulosus* Ayres, yellow-spotted rockcod.

Family ANOPLOPOMATIDÆ.

Anoplopoma fimbria Pallas, black cod.

Family HEXAGRAMMIDÆ.

Hexagrammos decagrammus Pallas, sea trout and *Ophiodon elongatus* Girard, blue cod.

Family COTTIDÆ.

Scorpænichthys marmoratus Ayres, cabezon; *Calycilepidotus spinosus* Ayres, and *Enophrys bison* Girard.

For detailed work, *Ophiodon elongatus* was taken as a type. The reason for choosing *Ophiodon* was partly because of its position between the 2 extremes of the suborder, but especially on account of its size (sometimes reaching a weight of 70 lbs.), and the ease with which it can be injected. Every effort has been made toward accuracy. Several specimens of each species compared have been studied, in order to eliminate the error that might come from variation in different individuals of the same species. Notwithstanding, omissions, if not errors, have probably crept in. The drawings, rude as they may be, were all made from a single dissection, with the exception of Pl. I, fig. 1, which is a combination of several dissections.

The material for this paper was collected by Chinese fishermen at Monterey Bay, Cal. The work was done at Stanford University and at the Hopkins Seaside Laboratory, and under the direction of Prof. C. H. Gilbert, to whom I am indebted for many favors and the facilities for research. Also I am under the greatest obligations to Prof. G. C. Price, of Stanford University, for a room at the Hopkins Laboratory; and to Mr. J. C. Brown of the University of Minnesota, for many favors.

II. TECHNIQUE.

1. Injecting Masses.

Nearly every injecting mass and color has been tried, but the most satisfactory, as well as the cheapest, proved to be a gelatin mass, colored with Berlin blue or carmine, and Hoyer's lead chromate yellow gelatin mass; or, for tracing out fine vessels and histological work, a saturated aqueous solution of Berlin blue may be used.

Berlin blue can be purchased in the form of a dried precipitate and this dissolved in water, but a more satisfactory solution is obtained by following the directions of Mayer (54, p. 310). A solution of 10 c.c. of tincture of perchloride of iron, or a saturated solution of ferric trichloride, in 500 c.c. of water is added to a solution of 20 grams of yellow prussiate of potash in 500 c.c. of water. This mixture is allowed to stand for 12 hours. The yellow fluid at the surface is then poured off, the remainder filtered and the filtrate washed with distilled water until the washings come through dark blue. Enough water is then added to completely dissolve the precipitate. This should make about a liter of concentrated solution of Berlin blue.

If a gelatin solution is desired, use from 10 to 20 parts of the Berlin blue solution to one of the gelatin. I usually take 25 grams of gelatin to 100 c.c. of water; heat in the same water bath with 200 or 300 c.c. of the Berlin blue solution. When the gelatin solution is melted, add to it, slowly, the Berlin blue solution; the mixture is then heated until the precipitate, which is usually formed, disappears. Then filter through a flannel. If the mass is to be kept some time, add a little chloral hydrate. For fish vessels it is best to inject the mass as cool as possible.

Hoyer's Yellow Lead Chromate Gelatin Mass (see Lee's Vade-Mecum, p. 304) is a very simple mass to make. Prepare 2 bottles of stock solution; in one, make a saturated aqua solution of potassium bichromate, and in the other a saturated solution of lead acetate. Then soak up 25 grams of gelatin in 100 c.c. of water; heat to melting point in a water bath; add 100 c.c. of the potassium bichromate solution. Afterward heat nearly to the boiling point; add 100 c.c. of the lead acetate solution, and filter through a flannel. It is best to make this

mass shortly before using. This mass has a beautiful yellow color, having a very fine precipitate, which easily passes through the fine capillary net-works of the gills, pseudobranchiæ, and retia mirabilia of the eye.

A *carmine solution* is prepared by mixing some carmine with water; enough ammonia is added to dissolve the carmine, giving it a dark brown color. The mass is then neutralized with acetic acid, and when neutral it will change to a bright red color. If desired to keep for some time, add chloral hydrate. Like the Berlin blue solution it can be injected as it is; or it can be mixed with a gelatin mass in the same proportions.

2. *Apparatus.*

The apparatus consisted of a number of glass cannulas of various sizes, fastened to short, but stout rubber tubes; a 4-oz. rubber syringe, and a $\frac{1}{2}$ oz. rubber syringe. The latter, when connected with a rubber tube and a small glass cannula makes the best kind of a hypodermic syringe.

3. *Mode of Procedure.*

When the arteries and veins are to be injected with different colors, it is best to inject the venous system first. This can generally be accomplished from the *hepatic vein* (Pl. I, fig. 1, Hep.V.). A ligature is placed under the vein and tied loosely; a slit is made in the anterior portion of the liver, and a large cannula attached to a rubber tube is forced cephalad in the vein into the *sinus venosus*. The blood was sucked into the tube, and then blown out; this process was repeated, until the sinus and other vessels were cleared of blood, and the cannula was again inserted into the vein and ligatured. Then the syringe was filled with the yellow injecting mass, but before connecting with the rubber tube, all the air possible should be sucked out of the tube, sinus, and other vessels. With a slow steady stroke the mass is forced into the sinus venosus; from thence through the heart to the gills; through the precava to the jugular and cardinal veins, and usually it would pass through the other hepatic vein and the venous capillaries of the liver, thus filling the portal system. If this fails, the portals can easily be injected from the *posterior mesenteric vein* (Pl. I, fig. 1; P.Mes.-

V.); or, if this vessel is absent, from one of the intestinal veins. If desirable to fill the caudal, neural, and hæmal veins, a separate injection of the *caudal vein* (fig. 1, Cau.V.) is usually required. The entire arterial system can be filled from one of the *gastric arteries* (fig. 1, L.Gas.A.), but an easier and more satisfactory way, especially if the fish has no air-bladder, is to make 2 injections of the *dorsal aorta* at a point marked X (fig. 1), shortly before it penetrates the kidney and posterior to the origin of the cœliaco-mesenteric and subclavian arteries. A cannula the proper size, having a rubber tube attached, was slipped cephalad into the vessel and ligatured. If the aorta is small, the rubber tube and cannula can be used as a blow pipe to help open it up. The syringe is then filled with the Berlin blue injecting mass; as much air as possible is sucked out of the tube and vessels before connecting the tube with the syringe; with a slow, steady movement, the mass is forced cephalad into the aorta, from whence it passes into the carotids, efferent branchial vessels, cœliaco-mesenteric and subclavian arteries, and finally in like manner, from the same place, the aorta is injected caudad, which fills the vessels of the kidney, reproductive organs, body wall, and tail.

In tracing out the small peripheral vessels of the head, fins, and viscera, I have found it very satisfactory to inject alone the head, fins and viscera of a 15 to a 40 pound fish. The head is severed dorsally several inches behind the skull, including the pectoral and ventral fins, being careful not to cut or injure any of the visceral organs. A ventral slit is then made through the entire ventral wall to the vent; the intestine is cut at the rectum, and the entire viscera pulled out with the head. In this manner the fish is cleaned, spoiling very little if any of the flesh, after which the 2 cut ends of the *cardinals* (Pl. I, fig. 1, L. & R.Car.V.), and the posterior end of the *ventral artery* (Pl. II, fig. 12, Ven.A.), if cut, were ligatured. Two injections, as described in the previous paragraph, were made; one from the *hepatic vein*, and the other cephalad from the cut end of the *dorsal aorta*.

In most cases it is best to make the dissections while the material is fresh. As a preserving fluid I find nothing better than formalin; it does not extract colors as does alcohol, and

its action toward gelatin is favorable, hardening it considerably. The coats of the eye are fixed in perfect shape, and such delicate organs as the kidneys are quickly hardened, so that one can cut cross-sections with a knife, which is a great help in tracing out the renal-portal system.

If a histological injection is required, slit the *sinus venosus* and wash out the blood vessels, cephalad, from the *dorsal aorta*; then inject with an aqua or thin gelatin Berlin blue mass, or with Hoyer's yellow chromate mass, freshly prepared. The mass is allowed to set and the injected organs are thrown in toto into Müller's fluid, or better still, cut up into small pieces and thrown into any well known fixing fluid that will not extract the colors. Injected material thus fixed can be kept some months in alcohol, but it is best to imbed as soon as possible.

If the bile vessels are to be injected, it can be accomplished by slitting the *ductus choledochus*, near its exit into the intestine or pyloric cæca. A hypodermic syringe filled with the Berlin blue mass is inserted into the duct, toward the gall-bladder, filling first the bladder, then the hepatic ducts, and finally, if successful, the gall-capillaries.

III. HISTORICAL REVIEW.

To Duverney (13),* in 1699, 62 years after the discovery of the blood-vascular system by Harvey, and 38 years after the discovery of the capillaries by Malpighi, belongs the honor of first explaining the structure of the fish heart; and 2 years later (14) he described and figured the circulation in and about the gills of the carp; he erred, however, in finding but one branchial vessel in a branchial arch. Monroe (48) in 1787, was the first to describe correctly the circulation in the gills. He injected the ventral aorta and examined the gill-filaments under a microscope; he also noticed the efferent branchial vessels, uniting to form the carotids, cœliaco-mesenteric, dorsal aorta, and the sub-clavians, and observed the coronary and other vessels coming from the ventral ends of the efferent branchial vessels; as well as the jugular, portal, and renal-portal systems. According to Müller (50), Albers (1) in 1806, was the first to notice the cho-roid gland of the eye, and observed that the vessels in the cho-

* All figures in brackets refer to bibliography at the end of the paper.

roid coat arose from this plexus. The first volume of Cuvier and Valenciennes' great work on fishes (11) issued in 1828, contains a short general description of the circulation of *Perca*, with 2 excellent plates, which show practically all the vessels, including the afferent and efferent pseudobranchial arteries, and 10 years later, Jones (41) carefully described and figured the retia mirabilia of the eye.

About this time marked the beginning of the classical writings of Hyrtl, Müller, Vogt, and Stannius. Between the years 1838 and 1872, Hyrtl published at least 7 different papers on the circulation of fishes, but unfortunately I have had access to only a few of them. Müller (50) tells us that in the first one (30) the author made a microscopical examination of the gill-filaments, and showed that they contained no lymphatic vessels, as had been claimed by some previous investigators. He also explained correctly the course of the blood from the hyoidean artery to the pseudobranchiæ, and from thence to the eye. With Hecht, he noticed the pseudobranchial artery coming from the circulus cephalicus. In 1852, Hyrtl (32) described with considerable detail the arterial system of *Lepisosteus*, and 6 years later the arterial system of the roaches (34). One of the best general works on the circulation of fishes is to be found in part IV of Müller's famous work on Myxinoiden (50), consisting of 130 pages and 5 plates. He takes up almost the entire circulatory system of cyclostomes, selachians, and several teleosts in a comparative way, going into great detail over the blood supply of the pseudobranchiæ, choroid gland, and air-bladder. Vogt's splendid monograph on the Anatomy and Embryology of the Salmon was published in 1845, but unfortunately I could get access only to the plates, of which several were devoted to the adult, and many others to the development of the circulatory system in the embryo. In Stannius' Handbuch der Anatomie der Wirbelthiere (74), there is a brief, but perhaps the best, general description of the circulation in the several groups of fishes; there are, however, no plates. The author does not go into quite as much detail regarding the blood supply of the pseudobranchia, eye, and air-bladder as Müller, but goes into more detail concerning the larger trunks and the vascular supply for the visceral organs.

During the last half century quite a number of important papers have appeared on the circulation of different species of fishes, or confined to the circulation of various organs, and a few are devoted to the embryology and physiology of the blood vessels. First under this head might be mentioned the first volume of Owen (58), which was issued in 1866. The author gives a very good comparative description of the circulation in several groups of fishes. Ten years later Stöhr (75), described the number and arrangement of valves in the conus arteriosus of selachians and ganoids. In 1880, Emery (24) put out his monograph on the genus *Fierasfer*. This volume contains a short, but accurate account of the circulatory system and 2 most excellent colored plates; the first one consists of a figure of the entire arterial system, a similar figure of the venous system, and several figures showing the blood supply in the kidneys; while the other plate is devoted to the blood vessels in the organs. The same year T. J. Parker published a paper, to which I have not had access, on the venous system of the skate, *Raja nasuta* (59). In 1884, McKenzie published a most excellent paper on the catfish, *Ameiurus catus* (52). He gives one figure showing the union of the efferent branchial arteries to form the carotids, dorsal aorta, etc., and finds the pseudo-branchiæ, though only rudimentary, located on the main internal carotid artery, and not on a branch of the external carotid or hyoidean artery as is the case with bony fishes in general. In Marshall and Hurst's Zoölogy (53), there is one figure and a very good description of the circulation of the dogfish, *Scyllium canicula*. By far the best account that we have of the circulation of selachians is found in T. J. Parker's memoir on *Mustelus* (60), which was published in 1886. It contains 47 pages and 4 most excellent colored plates. The author gives a brief synonymy of the blood vessels, and his methods of investigation. Unfortunately I did not gain access to this valuable paper, until my own work was nearly completed. Mayer (55), in 1888, gives a detailed account of the circulation in the fins of selachians, with 2 colored plates. The author gives the technique employed and favors an aqua solution of Berlin blue for an injection mass. The so-called peripheral lymphatic vessels described by Hyrtl, Müller, and Stannius, he considers as

veins. An excellent account of the embryology of the heart and blood vessels was given by Hoffman (39) in 1893. In Vogt and Yung's *Anatomie*, vol. 2, there is found a brief, but excellent account of the circulatory system of the perch, with 2 colored plates. T. J. Parker (61) in his *Zoöatomy*, 1895, gives the general outline of the circulation in the skate, *Raja nasuta*, with 2 figures, and also a similar description and one figure on the circulation of the cod, *Gadus morrhua*. In the first few pages of Allis' paper on *Amia* (3), there is a detailed account of the circulation in the head region, illustrated by several beautiful colored plates. To Jordan and Evermann (45) in 1898, we are indebted for a systematic arrangement of the fishes and fish-like vertebrates of North America. In 1900, Allis (4) published a complete account of the development of the pseudo-branchial circulation in *Amia*, and lastly, Brünning (10) in the same year was the first to work out in any detail the physiology of the blood vascular system of fishes. To this list might be added the general comparative anatomies of Gegenbour (26 and 27) and Wiedersheim (86 and 87).

SECTION II. TEXT.

IV. GENERAL SURVEY OF THE BLOOD VESSELS IN OPHIODON.

Since the blood of a fish passes around in a circle, it matters but little where we begin. A simple glance at Pl. I, fig. 1, will give an idea of the general course of the blood. The entire venous blood is poured into the *sinus venosus* (Pls. I and II, figs. 1 and 12; Sin.Ven.), through 6 large sinus-like vessels. From the rear come the *hepatic veins* (Pls. I and II, figs. 1 and 12; Hep.V.), which through the capillaries of the liver receive the *portal veins* (Pl. I, figs. 1, 6, and 11; L. and R.Por.V.), bringing the venous blood from the viscera; and the *ventral veins* (Pl. I, fig. 12; L. and R.Ven.V.) conveying the blood from the ventral or pelvic fins and the body walls. From either side, the sinus venosus receives 2 large lateral trunks. The posterior ones or *subclavian sinuses* (Pl. II, fig. 12; Sub.S.) are the smaller, containing venous blood from the outer or abductor muscles of the pectoral fins; and the anterior or larger ones are the *precaval veins* or *ductus cuvieri* (Pl. II, fig. 12; Prec.V.), which receive the venous blood from the rest of the

body. Close to the sinus venosus the right precava receives the *inferior jugular vein* (Pls. I and II, figs. 1 and 12; I.J.V.), returning the venous blood from the branchial muscles and the pharynx. Passing dorsad around the œsophagus, each precava arises at the ventral surface of the head kidney from 2 large trunks; the cephalic vessels or *jugular veins* (Pls. I and II, figs. 1, 5, and 12; R. and L.J.V.) convey the venous blood from the face, nose, eyes, brain, and dorsal branchial muscles and their arches; and the caudal vessels or *cardinal veins* (Pl. I, figs. 1 and 5; R. and L.Car.V.) vary greatly in length and in size. The short left cardinal returns blood only from the left head kidney; while the large right cardinal arises in the posterior end of the kidney and through the *renal veins* (Pl. I, figs. 1 and 10; A. and E.Ren.V.) receives blood from the *caudal vein* (Pl. I, figs. 1 and 10; Cau.V.) coming from the tail in addition to collecting blood from the thoracic walls, reproductive organs, and viscera.

From the sinus venosus, the blood passes into the *auricle* or *atrium* (Pls. I and II, figs. 1 and 12; Aur.), through the *ventricle* (Pls. I and II, figs. 1 and 12; Ven.) into the *bulbus arteriosus* (Pls. I and II, figs. 1 and 12; B.Art.), from whence it is forced through the *ventral aorta* or *branchial artery* (Pls. I and II, figs. 1 and 12; V.Ao.) into 4 pairs of *afferent branchial arteries* (Pls. I and II, figs. 1 and 12; A.Br.A.), (the third and fourth pairs, however, arise as one trunk, but soon divide), which run in the posterior grooves of their corresponding arches. These vessels exhaust themselves in numerous *afferent filament arteries* (Pl. I, fig. 2; A.Fil.A.), which pass along the inner edge of each branchial filament and which are collected on the opposite or outer side by the *efferent filament arteries* (Pl. I, fig. 2; E.Fil.A.), after having passed through a fine capillary network, where the blood is purified by the oxygen held, physically, in the water. These efferent filament arteries, containing pure arterial blood reunite, forming the *efferent branchial arteries* (Pls. I and II, figs. 1, 5, and 12; E.Br.A.), which run parallel, but cephalad to the afferent branchial arteries. From the ventral ends of these efferent vessels are given off the *hyoidean artery* (Pls. I and II, figs. 1 and 12; Hyo.A.) for the hyoid arch and tongue, and which

anastomoses with the facialis-mandibularis branch of the external carotid forming the mandibular artery; the *pharynx artery* (Pl. II, fig. 12; Phar.A.) for the ventral branchial muscles, from which the *coronary artery* (Pls. I and II, figs. 1 and 12; Cor.A.) arises; the *ventral artery* (Pls. I and II, figs. 1 and 12; Ven.A.) for the ventral or pelvic fins and the ventral body walls; and several smaller arteries, which will be described in detail further on. Dorsally the efferent vessels send off anteriorly the *common carotid arteries* (fig. 1; C.Car.A.), which supply the face, orbit, nose, and brain; and posteriorly the efferent branchial vessels unite in forming the *celiaco-mesenteric artery* (Pl. I, figs. 1 and 5; Cœ.Mes.A.) for the viscera; the *subclavian arteries* (figs. 1 and 5; Sub.A.) for the pectoral fins; and the *dorsal aorta* (figs. 1 and 5, D.Ao.) for the body walls, tail, kidney, and reproductive organs. The union of these efferent branchial vessels to form the internal carotids anteriorly and the dorsal aorta posteriorly, forms what is known as the *circulus cephalicus*.

V. HEART.

This organ, which is inclosed in the triangular cardiac space, lies in the ventro-median line directly cephalad of the pectoral arch. The pharynx forms the roof of this cavity, the thick sternohyoideus muscle the floor, and together with the pharyngo-clavicularis internus muscles it makes up the lateral walls; while the aponeurotic membrane forms the posterior wall that separates the cardiac cavity from the visceral cavity. This chamber is lined with the pericardium, which, like the peritoneum, consists of a parietal and visceral layer; the former lines the cavity and the latter loosely envelops the heart, being attached anteriorly to the ventral aorta in the region of the first afferent branchial vessels and posteriorly to the dorsal and ventral wall of the precava. The space between the parietal and visceral layers is known as the outer pericardial cavity or pericardial lymphatic sinus, for it is in direct communication with the lymphatics; while the space between the heart and the visceral layer is known as the inner pericardial or pericardial cavity proper. No connections were noticed between these 2 cavities.

As in the other vertebrates the heart is the center of activity,

however, it contains only venous blood. The heart proper consists of 2 chambers: a dorsal one, the auricle, and a smaller ventral one, the ventricle. The entering blood comes into the auricle posteriorly, from the thin-walled sinus venosus, from whence it is forced ventrad into the ventricle and then out anteriorly into the elastic bulbus arteriosus.

Sinus Venosus (Pls. I, II, and VI, figs. 1, 12 and 39; S. Ven. and Sin. Ven.).—When inflated the dimensions of this thin-walled sinus are about equal. In a 40 lb. *Ophiodon* this chamber measured 38 mm.¹ in length from the entrance of one precaval vein to the other, 32 mm in breadth from the sinu-auricular valves to the entrance of the hepatic veins, and 28 mm. in height at the center. The large sinus-like vessels emptying into this sinus have their inner edges reflected inward in the form of flaps, which tend partly to close the openings in case of a reverse current. In a like manner the walls of a sinus venosus, after having united with the outer connective tissue layer of the auricle, are reflected inward to form the *sinu-auricular valves* (Pl. VI, fig. 39; S.A.V.). Some fishes are said to have a dorsal and a ventral flap, but in *Ophiodon* they have become fused, forming a continuous circular flap, which decreases the size of the sinu-auricular opening by at least one-half.

Auricle (Text-figs. 1 and 2; Pls. I, II, and VI, figs. 1, 12, 39 and 40; Aur.).—This triangular, saddle-shaped reservoir, convex above and concave below, is much larger than the ventricle, when inflated. It extends over three-fourths of the ventricle; its anterior apex extends cephalad over the bulbus arteriosus some little distance, and posteriorly the auricle ends in 2 lateral horns. In this specimen the auricle measured 34 mm. in length, from its apex to the sinu-auricular valves, and if the posterior horns were included, the length would have been increased by at least 10 mm. The greatest width is in the neighborhood of the posterior horns, where it is 40 mm., and the greatest height amounted to something like 22 mm. The walls of this chamber consist of 2 layers, an outer coat of connective tissue

¹All measurements pertaining to the heart were taken from a 40 lb. *Ophiodon*'s heart, which had previously been injected with a gelatin mass and hardened in formalin.

(Text-figs. 1 and 2, and Pl. VI, fig. 39; C.T.) and an inner coat composed of muscle bands, the *trabeculae carneæ* (Pl. VI, fig. 39; T.C.A.). These muscle bands run in every direction, but mostly dorso-ventrad, and between these bands there are large blood cavities, which increase in size toward the central cavity,

FIG. 1.

the muscular layer becoming more and more compact toward the surface. The central cavity occupies a large portion of the auricle and is continued into the posterior lobes. Penetrating the floor of the auricle, a little caudad of the center, is the *auriculo-ventricular opening* (Pl. VI, fig. 39; A.V.O.), through

which, by the contraction of the trabeculæ of the auricle, the blood from the auricle is forced into the ventricle. In order to prevent a back-flow of blood, this passage can be entirely closed by 2 *auriculo-ventricular valves* (Pl. VI, figs. 39 and 40; and Text-fig. 1; A.V.V.), respectively anterior and posterior in position and which when closed appear like 2 inverted cups from the auricle side, having their inner edges free. These valves are formed by the union and a thickening of the outer layer of connective tissue from the auricle and the ventricle.

Ventricle (Text-figs. 1 and 2; Pls. I, II, and VI, figs. 1, 12, 39 and 40; Ven.). — The ventricle, which is 42 mm. long by

FIG. 2.

27 mm. wide in this specimen, is shaped something like a 4-sided pyramid. Beginning bluntly, it gradually increases in width and then rapidly tapers down into a posterior apex. The ventricle has one more layer than the auricle. Outside is the

connective tissue layer (Text-figs. 1 and 2, and Pl. VI, fig. 39, C.T.), which is continuous with the corresponding layer of the auricle and where such union takes place, the layer becomes much thicker (see Text-fig. 1). The *trabeculae carneae* of the ventricle (Pl. VI, fig. 40; T.C.V.) resemble the trabeculae of the auricle close to the outer connective tissue layer, the blood cavities being very small. In addition to the 2 layers of the auricle, the ventricle has a thick *muscular layer* (Pl. VI, fig. 40; M.L.) between the trabeculae carneae and the outer connective tissue layer, containing no blood spaces. The *central cavity of the ventricle* (Pl. VI, figs. 39 and 40; C.C.V.), which runs close to dorsal wall, is much smaller than the central cavity of the auricle. The anterior end of this cavity is continuous with the posterior end of the bulbus arteriosus, which represents the well developed *conus arteriosus* (Pl. VI, fig. 40; C. Art.) of the Elasmobranchs and Ganoids. The entrance into the conus arteriosus is guarded by 2 *semi-lunar valves* (Text-fig. 2 and Pl. VI, fig. 40; S.V.), dextrad and sinistrad in position and having their inner margins free. These valves are similar to the auriculo-ventricular valves, except that each valve has 2 cephalic processes, which continue along the dorsal and ventral walls of the bulbus arteriosus. A reverse current, caused by a retraction of the elastic walls of the bulbus, would entirely close these valves, allowing no blood to return to the ventricle.

Bulbus Arteriosus (Pls. I, II and VI, figs. 1, 12 and 40, and Text-fig. 2; B. Art.). — After leaving the ventricle the bulbus rapidly increases in diameter and then gradually tapers down into the *ventral aorta* or *branchial artery* (Pls. I. and II, figs. 1 and 12; V.Ao.), which gives off the paired afferent branchial vessels to the gills. The walls of the bulbus are quite thick and the internal layers are thrown into *longitudinal ridges* or *folds* (Pl. VI, fig. 40; L.F.). The bulbus is richly supplied with blood vessels, which will be described later on.

Microscopical Structure of the Heart (Text-figs. 1 and 2). — A transverse section through one of the auriculo-ventricular valves (Text-fig. 1) shows us that the outer connective tissue layer is greatly thickened in the dorsal portion of the auricle and at the union with the same layer of the ventricle. As in other vertebrates the muscle fibers are striated and run in all direc-

tions, but for the most part they can be grouped under the head of *longitudinal muscle fibers* (Text-fig. 1, L.M.) and *transverse muscle fibers* (Text-fig. 2, T.M.). At various places the muscle fibers penetrate the connective tissue layer and very often fibers from the auricle would pass entirely through this layer into the ventricle. The auriculo-ventricular valves are merely a portion of the combined outer connective tissue layer, having their inner margins free, but having their outer edges securely bound down by muscle fibers. About the only difference in structure between the auricle and the ventricle, aside from the relative sizes of their central cavities, is the difference in the density of their muscle fibers. In the ventricle the blood cavities are very small, while in the auricle they are of considerable size, but growing smaller peripherally, and in the ventricle these cavities give place entirely to muscle fibers, peripherally. Cephalad in the ventricle the connective tissue gradually increases about the central cavity, marking the beginning of the conus arteriosus. In 2 places folds of connective tissue pass entirely through the central cavity or conus as it is at this place. They are the semi-lunar valves (Text-fig. 2, S.V.). In places can be seen traces of *elastic muscle fibers* (Text-fig. 2, E.M.F.) and *round endothelium cells* (Text-fig. 2, End.). While it is not the purpose of this paper to demonstrate the presence or absence of a layer of endothelium lining the central cavity of the heart, it may be said, however, that my sections did not show anything that I could positively identify as endothelium, until the origin of the conus was reached; nevertheless a silver impregnation would have doubtless revealed its presence. The walls of the bulbus are formed from 3 coats. The external coat, *tunica externa* or *adventitia* presents no peculiarities; it is composed of longitudinal bundles of connective tissue, in which run the main nutrient vessels. Next comes the *tunica media* or middle coat, which is very thick and forms the longitudinal folds shown in fig. 40, which decrease in height as you go toward the ventral aorta. This tunic is constructed out of circular muscle fibers, in which run many white elastic fibers. The internal coat or *tunica interna*, which is made up of a longitudinal network, is bounded internally by a layer of large round endothelial cells.

VI. PERIPHERAL DISTRIBUTION OF THE ARTERIES.

1. *Branchial Arteries.*

As has already been stated in the paragraph on the general survey of the blood vessels, the *afferent branchial arteries* (Pls. I and II, figs. 1 and 12; A.Br.A.) are paired vessels, which convey the venous blood from the *ventral aorta* or *branchial artery* (Pls. I and II, figs. 1 and 12; V.Ao.) to the branchial filaments.¹ They arise as 3 paired trunks from the ventral aorta. The most cephalic pair supply the filaments of the first branchial arches; the second pair the filaments of the second branchial arches; and the third pair soon divide, the anterior forks supplying the third pair of branchial arches and the posterior forks, the last or fourth pair of branchial arches.² All of these vessels, which very closely resemble one another, run in the grooves of their respective arches and gradually exhaust themselves by giving off numerous afferent filament arteries throughout their entire dorsal course.

The *Afferent Branchial Filament Vessels* (Pl. I, fig. 2; A.Fil.A.) of 2 adjacent filaments arise as paired vessels, and running in a caudal direction along the inner or hypotenuse margins of their respective filaments, gradually exhaust themselves in numerous *afferent filament cross-vessels*, which are only about 60 μ apart. Proximally these vessels attain a considerable length, but gradually decrease in length distally. Each cross-vessel terminates in a dorsal and a ventral vessel, from which the *filament capillary network* (Pl. I, fig. 2; Fil. Net.) arises. This network lies in a dorso-ventral plane in-

¹ A gill or *holobranch* is composed of a double row of filaments or 2 *hemibranchs* attached to the concave or posterior side of each branchial arch. These filaments have the form of right-angled triangles, attached by their short sides to the arches and the hypotenuse sides of each pair face one another. Each pair of filaments is not separated by a cartilaginous rod as is the case with the Elasmobranchs, but they usually overlap one another to some extent at their bases.

² This appears to be the normal arrangement among the Teleosts; while in the skate one trunk may supply several branchial arches, and in the ratfish (*Hydrolagus*), I have observed that the ventral aorta gives off a pair of vessels for each pair of branchial arches.

closed in a vascular plate¹ and is separated from the current of water passing between the gills by a thin membrane. By osmosis the carbon dioxide from the blood is exchanged for the oxygen held in the pores of the water. In a like manner the pure blood is collected into a pair of dorso-ventral vessels, which unite, forming a short *efferent filament cross-vessel*. These vessels in turn form the *efferent branchial filament arteries* (Pl. I, fig. 2; E.Fil.A.), which run cephalad along the outer margins of the filaments and which in turn empty into and form a common trunk, running in the posterior groove of each branchial arch, namely, the efferent branchial artery.

These *efferent branchial arteries* (Pls. I and II, figs. 1, 2, 5, and 12; E.Br.A.) very closely resemble one another. They run parallel, but cephalad to the afferent branchial vessels; beginning ventrally they increase in size dorsally. For the most part the efferent filament arteries are poured directly into the main efferent branchial trunks, but dorsad and ventrad they empty into a branch of that vessel. The ventral branch takes its origin from paired vessels, which lie immediately caudad and to either side of the large efferent branchial trunk. They receive first the most ventral pair of efferent filament arteries; then in their dorsal course take up in succession from either side the several following efferent filament arteries, and after having received 20 or 30 such vessels, unite, forming a short trunk, which empties into the main efferent branchial trunk from the rear. In like manner the dorsal branch arises as a paired vessel and returns the blood from several of the most dorsal filaments. There is also a gradual variation in the point where the various efferent branchial arteries leave their respective branchial arches. The first or most anterior efferent vessel follows along the posterior edge of the cerato- and epi-branchials some little distance beyond the dorsal-cephalic bend; while the fourth or posterior efferent branchial vessel leaves the cerato-branchial a little below the dorsal-cephalic bend; and the efferent branchial vessels of the second and third branchial arches come in midway between these extremes, forming a regular series of intergradations. Ventrally the first, second

¹ Each branchial filament is divided up into numerous parallel vascular plates or lamellæ, which lie in dorso-ventral planes.

and third efferent branchial arteries on one side anastomose with the corresponding trunks of the opposite side. From either side of the ventral point of union of the first pair of efferent vessels, a large *hyoidean artery* (figs. 1 and 12, Hyo.A.) is given off to the hyoid arch and mandibular region. The ventral points of union of the second and third pairs of efferent branchial arteries mark the source of the *ventral artery* (Pls. I and II, figs. 1 and 12; Ven.A.); and the *pharynx artery* (Pl. II, fig. 12; Phar.A.) may arise from either of the third efferent branchial arteries. From the dorso-cephalic surface of the first pair of efferent branchial vessels, the 2 *common carotid arteries* (Pl. I, figs. 1 and 5; C.Car.A.) are given off cephalad; continuing dorso-caudad, the first efferent trunk unites with the second to form the *first or anterior epibranchial artery* (Pl. I, fig. 5; Epbr.A.₍₁₎), and in like manner the third and fourth efferent branchial vessels unite to form the *second or posterior epibranchial artery* (Pl. I, fig. 5; Epbr.A.₍₂₎). The epibranchial vessels on one side unite with the corresponding trunks on the opposite side, forming a *common chamber* (Pl. I, fig. 5; C.C.), which lies in a median line ventrad of the basi-occipital. This chamber is the source of several large trunks; the *dorsal aorta* (Pl. I, figs. 1 and 5; D.Ao.) arising from the left posterior dorsal corner; the *cœliaco-mesenteric* (Pl. I, figs. 1 and 5; Cœ. Mes.A.) below and to the right; and the *common subclavian trunk* (Pl. I, fig 5) lies above the aorta and the cœliaco-mesenteric artery. In one case the subclavians were seen to arise separately. The left one had its origin in the same place as the common subclavian trunk, and the right one came from the cœliaco-mesenteric artery.

2. *Arteries Arising From the Ventral Ends of the Efferent Branchial Arteries.*

First under this head might be mentioned the 2 little *hyo hyoid-eus inferior arteries* (Pl. II, fig. 12; Hys.A.), which arise from the cephalic surface of the first efferent branchial arteries just before they unite ventrally. These vessels run cephalad a short distance and then spread out laterad over the dorsal surface of their respective muscles.

Hyoidean Arteries (Pls. I and II, figs. 1 and 12; Hyo.A.). — A short distance above the source of the inferior hyo hyoideus arteries, 2 large hyoidean arteries are given off to the hyoid arch and the adjacent region. After reaching the hyoid arch from the inside, a little behind the hypohyals, the main trunk runs along the dorsal surface of the cerato- and epi-hyals; making a dorsal bend in front of the interhyal it crosses under the preopercular, and after passing through a foramen, which is formed by the symplectic, hyomandibular, preopercle, and quadrate, anastomoses with the *facialis-mandibularis artery* (Pl. I, fig. 1; F.Man.A.). In the embryo the hyoidean artery probably furnished the entire blood for the pseudobranchia; the current of blood in the facial-mandibular artery was dorsad toward the carotids. Also in the adult it would be possible for the blood from the hyoidean artery to flow dorsad in the facial-mandibular artery as well as ventrad, however, since the facial-mandibular is a much larger artery than the hyoidean, it is not probable that much of the blood from the hyoidean artery runs counter to the current of the facial-mandibular artery. It also might be possible at times for the blood in the hyoidean artery to flow ventrad, that is toward the efferent branchial artery. From Müller's (50), Stannius' (74), and Emery's (24) descriptions, one would infer that the hyoidean artery in most bony fishes supplied the pseudobranchia, but in *Ophiodon* the blood supply for the pseudobranchia, which will be considered later, comes from a branch of the external carotid artery.

The first branch to be given off from the hyoidean artery is the *lingual artery* (Pl. II, fig. 12; Lin.A.). This vessel leaves the hyoidean artery close to the efferent branchial artery, shortly before the hyoidean artery reaches the hyoid arch, and each lingual artery runs cephalad along the ventral surface of the glossohyal. Immediately after the hyoidean artery reaches the hyoid arch it gives off the *geniohyoideus artery* (Pls. I and II, figs. 1 and 12; Ghs.A.) to the geniohyoideus muscle. One of these arteries is much longer than the other; sometimes it is the right and again it is the left. In the specimen from which fig. 12 was drawn, the right artery was the longer; it passed entirely around to the outer ventral surface of the ceratohyal and then curved cephalad, pass-

ing obliquely along the ventral surface of the right geniohyoideus muscle and above the right hyohyoideus inferior muscle. When the median line between the 2 geniohyoideus muscles is reached this vessel bifurcates, one branch running along the ventral surface of each geniohyoideus muscle. Both of these forks supply also the intermandibularis muscle. The short geniohyoideus artery, which is the left one in this specimen, supplies only the posterior part of the left geniohyoideus muscle. The largest of the branches of the hyoidean artery is the hyoid arch artery proper, which has been designated as the *branchiostegal artery* (Pls. I and II, figs. 1 and 12; Br.O.A.). This vessel is given off a little cephalad of the interhyal and runs along the outer ventral edge of the epi- and cerato-hyals. In the region of each branchiostegal ray an artery is given off ventrad to supply the hyohyoideus superior muscles. In *Scorpaenichthys* one branchiostegal artery does not supply all of the superior hyoideus muscles. Three or 4 such vessels pass over the outer surface of the epi- and cerato-hyals and supply from 1 to 3 hyohyoideus superior muscles; the last one evidently corresponds to the single branchiostegal artery of *Ophiodon*.

What might be called the *thyroid artery* (Pl. II, fig. 12; Thy.A.) arises either from the second right or the second left efferent branchial artery. In Fig. 12 it arises from the second right efferent artery, flows cephalad under the ventral aorta and anastomoses with the first efferent branchial artery. Along its short course 2 or 3 small branches could be traced to the thyroid gland, one of them supplying also the second left obliquus ventralis muscle.

Pharynx Artery (Pl. II, fig. 12; Phar.A.).—This vessel may have its source from the third left or the third right efferent branchial artery. In the specimen from which fig. 12 was drawn it arose, caudad, from the third right efferent branchial vessel and, passing obliquely over the ventral aorta it bifurcates in the region of the combined afferent trunk of the third and fourth branchial arches. The smaller *right pharynx artery* (Pl. I, fig. 12; R.Ph.A.) supplies the right side of the pharynx, the transversus ventralis muscle, and the right pharyngo-clavicularis externus and internus muscles; while the

larger *left pharynx artery* (Pl. II, fig. 12; L.Ph.A.) supplies the pharynx and similar muscles on the left side. Soon after the left pharynx artery leaves the main stem it gives off the large *coronary artery* (Pls. I and II, figs 1 and 12; Cor.-A.) for the heart. For some little distance this vessel runs along the dorsal surface of the ventral aorta and then divides into a dorsal and a ventral trunk. The *dorsal coronary artery* (Pl. II, fig. 12; D.Cor.A.) continues along the dorsal surface of the ventral aorta and bulbus arteriosus to the heart as the principal vessel. Usually this vessel bifurcates in the region of the conus arteriosus, one branch penetrating directly into the muscular layer of the ventricle, while the other is a superficial vessel, distributing itself over the dorsal surface of the ventricle; or sometimes both may be superficial vessels. It is probable that these vessels also supply the auricle, although I have never been able to trace them further than the ventricle. Each of these vessels gives off a small artery, which encircles the bulbus and anastomoses on the ventral side with the ventral coronary artery, and from this circular artery several small vessels are given off to the bulbus and the ventricle. The *ventral coronary artery* (Pl. II, fig. 12; V.Cor.A.), which is much smaller than the dorsal vessel, also runs caudad in the outer coat of the ventral aorta, but it supplies only the ventral walls of the ventral aorta and the bulbus. None of its branches reaches the ventricle. In *Scorpaenichthys* the pharynx arteries arise as separate arteries from the second pair of efferent branchial arteries, and the coronary artery comes from the left pharynx artery, close to its point of origin from the efferent branchial vessel.

The Ventral Artery (Pls. I and II, figs. 1 and 12; Ven.A.) is the largest of any of the vessels arising from the ventral ends of the efferent branchial arteries. In *Ophiodon* this vessel has its origin from the ventral union of the second and third pairs of efferent branchial arteries. This does not appear to be the common arrangement among other bony fishes; in *Hexagrammos*, *Scorpaenichthys*, and *Sebastodes* the ventral artery has its source from the second pair of efferent branchial vessels. Continuing caudad along the ventral surface of the pericardial

cavity a little to the right of the median line, the ventral artery gives off numerous branches to the sternohyoideus muscle. In the specimen from which fig. 12 was drawn, a vessel was noticed branching off to the left, passing horizontally under the ventricle, and terminating on the left precaval vein in the neighborhood of the left subclavian sinus. Directly caudad of this vessel and a little cephalad to the crossing of the sinus venosus, the ventral artery sends off a pair of vessels to the ventral muscles of the pectoral fin. Each of these *hypobranchial arteries* (Pl. II, figs. 12 and 14; Hypobr.A.) runs a short distance caudad between the sternohyoideus and the pectoral profundus adductor muscle, and then curves slightly dorsad, passing between the inner surface of the coracoid and the pectoral profundus adductor muscle, giving off at least two branches to the inner surface of the muscle; then curving slightly ventrad, penetrates the basal canal of the pectoral rays,¹ and anastomoses in this canal with the *internal subclavian artery* (2) (Pl. II, fig. 14; I. Sub.A.₍₂₎), but before entering this canal the hypobranchial gives off a dorsal branch which passes between the pectoral profundus muscle and the brachial ossicles, supplying the inner surface of the muscle. Continuing caudad, the ventral artery passes under the sinus venosus between the pelvic bones, giving off arteries to the body wall, the ventral or pelvic fin muscles, and the ventral rays. The first constant artery of any size to be given off from the ventral artery after it reaches the ventral fin musculature is one which comes out ventrad in a median line to the outer surface of the protractor muscle of the pelvic arch, where it divides at nearly right angles, one branch supplying the left, the other the right protractor muscle of the pelvic fins and the very large abductor muscle of the ventral spine (fig. 12; Ab.V.S.). At various intervals, usually alternating with the veins, the *ventral intercostal arteries* (Pl. II, fig. 12; V.Intc.A.) are given off between every alternate pair of myotomes, and they anastomose with the corresponding dorsal intercostal arteries. The ventral artery

¹ Each pectoral fin ray consists of 2 separate halves, which are concave inside and convex outside, and where their bases overlap the brachial ossicles in their attachment to the shoulder-girdle, there is formed a rather large canal at the base of the pectoral fin.

also sends off several branches to the other abductor and adductor muscles, and shortly before the pelvic bones become united posteriorly, the ventral artery makes a short dorsal bend and bifurcates at right angles, one branch going to the basal canal of the right ventral fin rays and the other to the left. Each terminal branch of the ventral artery exhausts itself by giving off a branch to the core of each ray; proximally this vessel runs in the center of the cavity, but soon divides, one branch continuing caudad along the right side of the cavity, the other the left. Usually from the left branch of the ventral artery, but often from the right, a median vessel is given off caudad, which passes along the ventro-median line between the 2 great lateral muscles and exhausts itself in numerous intercostal arteries.

This series of complicated vessels arising from the ventral ends of the efferent branchial arteries and anastomosing with a trunk of the subclavian artery may be comparable to the vessels described by Müller (pp. 36 and 37) as *epigastrische Arterien*, and the ventral artery or *ramus epigastricus decedens* of Müller may be analogous to the *mammaria interna* of mammals.

3. *Carotid Arteries.*

The short *common carotid arteries* (Pl. I, figs. 1 and 5; C.Car.A.) arise from the dorsal-cephalic corner of the first efferent branchial arteries, and passing cephalad a short distance, about 1 cm., divide into the large external and internal trunks.

(a). *External Carotid* or *Carotis Posterior Artery* (Pls. I and II, figs. 1, 5 and 15; E.Car.A.). — This vessel at once makes a dorsal-cephalic curve, passing through a foramen formed by a lateral process of the prootic, in company with, but directly below the jugular vein. Leaving this canal with the *infraorbitalis* or *truncus buccalis-maxillo-mandibularis* and just ventrad and caudad of the external jugular vein, the external carotid passes over the dorsal edge of the *hyomandibular*, along the posterior border of the orbit, and then runs ventro-caudad beneath the levator muscle of the palatine arch and the adductor *mandibulæ* muscles. It passes along the inner side of

the metapterygoid, and after receiving the hyoidean artery comes to the outer surface through a foramen between the symplectic, hyomandibular, preopercular, and quadrate bones. This combined vessel, which may be designated as the *mandibular artery* (Pl. I, fig. 1; Man.A), makes a sharp cephalic bend, passing over the outer surface of the quadrate bone and then curving inward around it to the inner surface of the mandible, where it terminates in 2 branches, which supply the adductor mandibulæ muscles. The main branch runs along the inner dorsal surface of the bone, while the smaller branch supplies the ventral portion of the muscles.

Along its ventro-cephalic course the external carotid sends off many branches in the facial region and receives one. The first vessel to be given off is the *sclerotic-iris artery* (Pl. II, fig. 15; Scl.Ir.A.). This rather small vessel arises from the dorsal surface of the carotid immediately after it leaves the canal formed by the prootic process. Close to its source the sclerotic-iris artery gives off caudad the most *anterior cranial cavity artery* (Pl. II and III, figs. 15 and 24; C.C.A.), which penetrates the skull through the middle and the largest of the prootic foramina, along the dorsal surface of the roots of the V nerve, and follows up the anterior surface of facialis portion of the ramus lateralis accessorius to supply the adipose tissue in the anterior portion of the cranial cavity. The main trunk, however, continues cephalad a short distance along the outer surface of the prootic dorsad of the gasserian ganglion, and here divides, one branch, the *sclerotic artery* (Pl. II, fig. 15; Scl.A.) continues cephalad, but laterad to the truncus supra-orbitalis or ramus ophthalmicus and the orbito-nasal vein. When the orbit is reached, instead of curving inward around the eye with the nerve and vein, it continues in a straight line over the dorsal surface of the eyeball in company with the sclerotic branch of the truncus supra-orbitalis and the sclerotic vein, to supply the adipose tissue surrounding the dorsal surface of the sclerotic coat. The other branch is the *iris artery* (Pls. II and III, figs. 13, 15 and 19; Ir.A.), which enters the skull through a foramen bounded by the dorsal process of the parasphenoid, the alisphenoid, and the prootic. Together with the

ciliary nerve and internal jugular vein it passes cephalad out of the skull through the large olfactory-optic foramen, then curving laterad in company with the ramus ciliaris longus and the iris vein it crosses under the orbito-nasal vein and the truncus supra-orbitalis, passing between the superior and external rectus muscles, gives off a branch to the latter (Pl. II, figs. 13 and 15; Ex.R.A.). Then running laterad across the posterior dorsal surface of the eyeball it penetrates the sclerotic coat in its median line, and continuing laterad in the silver layer of the choroid until the iris is reached, where, with the ramus ciliaris longus, it bifurcates into 2 ventral vessels, which supply at least the dorsal half of the iris. The normal arrangement of the iris vessels is first the iris vein, then the ramus ciliaris longus, and finally the iris artery, but in several cases I have observed the artery curving cephalad and passing between the nerve and the vein.

The second vessel is given off a little below the sclerotic-iris artery; and after making a rather sharp caudal curve terminates in the levator arcus palatini muscle. The next vessel is the *facialis-maxillaris artery* (Pl. I, fig. 1; F.Max.A.) which arises cephalad from the external carotid in the region of the orbit, and passes obliquely over the external jugular vein and the ramus mandibularis or the ramus maxillaris inferior, where it gives off a large ventral branch, the *facial artery* (Pl. I, fig. 1; F.A.), for the adductor mandibulæ muscles. This branch runs along the lateral surface of the deeper portion of the adductor mandibulæ, giving off numerous branches to the adductor muscles, but does not follow the nerve to the mandible. The main portion of the facialis-maxillaris artery proceeds along the floor of the orbit in the adductor arcus palatini muscle, to which it gives off numerous branches, and when the level of the nasal sac is reached it receives a much larger artery from the *orbito-nasal artery* (Pls. I and III, figs. 1 and 17; O.N.A.), which is a branch of the internal carotid artery.¹ This combined vessel continues in a cephalic direction, supplying the region directly

¹ McKenzie (52, p. 427) mentions the crossing of the branches of the external and internal carotids in the neighborhood of the nasal sac, in *Ameiurus* but nowhere have I met with the statement of their union.

behind the maxilla, and sends one branch ventro-caudad along the outer ventral surface of the adductor mandibulæ muscle.

As the external carotid artery passes behind the metapterygoid it gives off the large *pseudobranchial* or *afferent pseudobranchial artery* (Pl. I, fig. 1; Ps.A.) caudad to the pseudobranchia. Passing behind the hyomandibular, the pseudobranchial artery gives off a good-sized vessel dorsad for the levator muscle of the palatine arch, and shortly before the pseudobranchia is reached the pseudobranchial artery bifurcates into a short dorsal branch and a longer ventral branch. These vessels are analogous to the afferent branchial arteries of the branchial arches. Like them they give off the nutrient pseudobranchial arteries, from which the nutrient filament arteries arise for the pseudobranchial filaments (not shown in fig. 3.), and at regular intervals an *afferent pseudobranchial filament artery* (Pl. I, fig. 3; A.Ps.Fil.A.) is given off to the outer margin of the filament, which is the side that lies closest to the hyomandibular bone. As is the case in the branchial filament this artery exhausts itself in numerous afferent cross-vessels, which by dividing form the vessels from which the *pseudobranchial filament network* arises. These cross-vessels are much shorter than the corresponding branchial vessels and are about 80μ apart, this being 20μ more than the distance between 2 branchial filament cross-vessels. The longest septum of a pseudobranchial filament and the inclosed capillary network is much longer than the corresponding branchial septum, but the network itself is much coarser. In a like manner the capillary networks become collected into short cross-vessels on the inner side of the filament, which unite in forming the *efferent pseudobranchial filament vessels* (Pl. I, figs. 3 and 4; E.Ps.Fil.A.). These vessels terminate in, and form a short dorsal, and a longer ventral artery, which lie immediately cephalad of the corresponding afferent vessels, and are analogous to an efferent branchial artery.¹ They unite in forming the important *ophthalmic*

¹ The pseudobranch is a hemibranch or half-gill. Although its capillary network is a trifle coarser than the network of a branchial filament and its afferent vessel comes from the external carotid artery, still it has much in common with a branchial filament. The septa containing the pseudobranchial capillaries are exposed to the same current of water that bathes the gills, and it is natural to

or *efferent pseudobranchial artery* (Pls. I, II and III, figs. 1, 5, 15, 19 and 20; Oph.A.), which supplies only the choroid coat of the eye.² This vessel pursues a dorso-cephalic course, passing along the outer posterior edge of the levator arcus palatini muscle to the parasphenoid bone; it then runs parallel to the parasphenoid for a short distance, and when the anterior surface of the dorsal parasphenoid process is reached, sends off a branch inward in front of this process to anastomose with the corresponding artery from the opposite side. Here the main stem bends dorsad nearly encircling the orbito-nasal artery, and passing between the inferior and internal rectus muscles in company with the ramus ciliaris brevis and the ophthalmic vein it follows along the posterior surface of the optic nerve, but before penetrating the sclerotic coat the artery makes a dorsal curve around the ciliaris brevis and the ophthalmic vein, and pierces the eyeball a little dorso-caudad of the optic nerve. After passing through the silver layer of the choroid it bifurcates in the vascular layer of the choroid into an *anterior choroid artery* (Pl. III, figs. 20 and 21; Chor.A.₍₁₎) and a shorter *posterior choroid artery* (Pl. III, figs. 20 and 21: Chor.A.₍₂₎). These 2 vessels have somewhat the shape of a horse-shoe, having its curved end dorsad and its open end ventrad. Radiating from the outer surface of this horseshoe-shaped vessel are numerous short vessels, which soon break up into smaller vessels, and these in turn break up into minute parallel capillaries, forming the arterial retia mirabilia (Pl. III, figs. 19, 20 and 21; A.Ret.M.) of the so-called choroid gland or vasoganglion, which has already been accurately described by Jones (41), Müller (50), Stannius (74) and Emery (24). Distally these capillaries reunite, forming the *choroid arteries* proper (Pl. III, figs. 20 and 21; Chor.A.), which supply the choroid with arterial blood. A section through the choroid and retina (Pl. III, fig. 21) shows us that the choroid vessels are arranged in

suppose that the arterial blood which passes through these filaments receives additional oxygen from the water.

²I have made several separate injections of the ophthalmic artery, cephalad, after it leaves the pseudobranchia to see if it had any connection with the other arteries, especially the orbitonasal artery with which it comes in such close contact; but no connection whatever was found.

2 layers; an outer layer of large arteries and veins, and an inner layer of capillaries. The capillary layer is separated from the retina only by the thin pigment layer of the choroid.

A little dorsad to the point of union of the hyoidean artery with the external carotid, the latter sends off, caudad, a smaller *posterior hyoidean artery* (Pl. I, fig. 1; P.Hyo.A.). Close to its point of origin this vessel gives off a dorsal branch, which runs in front of the preopercular and directly behind the ramus mandibularis VII, supplying the inner side of the deeper adductor mandibulæ muscle. Passing ventro-caudad through the same foramen as the hyoidean artery it runs parallel with it. In its course along the inner side of the preopercular it passes along the dorsal surface of the interhyal a little below the hyoidean vein; then curving around the ventral edge of the epihyal it comes to lie above the vein, finally terminating in several vessels to the hyohyoideus superior muscle in the region of the last branchiostegal ray.

(b) *Internal Carotid* or *Carotis Anterior Artery* (Pl. I, figs. 1 and 5; I.Car.A.). — This vessel after leaving the common carotid bends inward, passes ventrad across the jugular vein to penetrate the internal carotid foramen (a foramen formed by the dorsal process of the parasphenoid, the parasphenoid, and the prootic bones) into the eye-muscle canal. Here it divides into a cephalic and a horizontal trunk. The former is the orbito-nasal artery, and the latter unites in the median line, above the parasphenoid, with the corresponding trunk from the opposite side, the combined trunk being the encephalic or brain artery.

The *encephalic* or *brain artery* (Pls. I, II and III, figs. 1, 5, 15, 23 and 25; Enc.A.) proceeds dorsad between the external recti muscles and penetrating the floor of the brain case directly cephalad of the hypophysis, and exhausts itself in 4 branches, which are given off at right angles to one another. The cephalic one may be designated as the anterior cerebral artery, the lateral ones as the right and left posterior cerebral arteries, and the small posterior one as the infundibular artery.

Soon after leaving the main stem the *anterior cerebral artery* (Pl. III, figs. 23 and 25; A.Cer.A.) divides; the 2 branches running parallel for a short distance in a sort of zig-zag course

along the ventral surface of the left optic nerve, and shortly before the olfactory lobes are reached they bear off laterad around the optic nerves, but, before leaving them, each vessel gives off a branch, which continues along the ventral surface of the nerve to the eye. This is the *optic* or *retina artery* (Pl. III, figs. 22, 23, and 25; Opt.A.), which gives off branches to the nerve and finally penetrates the eye-ball a little cephalad of the nerve. Once inside the retina it continues along the retina fissure (see fig. 22), giving off branches to either side and especially to a whitish gland-like body situated on the side of the fissure close to the falciform process. The main portion of the artery, however, breaks up on the falciform process, the campanula Halleri, and even extends over on the lens. It is also probable that the retina receives nourishment from the choroid arteries, which are separated from the retina only by the thin pigment layer of the choroid. The main anterior cerebral artery after curving around the optic nerve divides into an anterior and a posterior portion. Close to the point of bifurcation the anterior branch sends forward a small vessel, which runs along the ventral surface of the olfactory nerve, but the main trunk passes inward and anastomoses with its fellow in the median line. This point of union marks the source of 2 vessels, a smaller dorsal one designated as the most *anterior cranial cavity artery* (Pl. III, fig. 23; C.C.A.), coming up between the olfactory lobes to supply the adipose tissue in the anterior region of the cranial cavity and a larger caudal vessel, which runs in a median line between the optic nerves and the cerebral hemispheres, giving off several branches to the latter through the median fissure. The posterior branch of the anterior cerebral artery is a superficial vessel; it follows caudad along the ventro-lateral surface of the cerebrum, passing between it and the optic nerves, and giving off superficial branches to the ventral surface of the cerebrum and the anterior surface of the mesencephal. Sometimes the right, but more often the left artery continues dorsad with the epiphysis as the *second cranial cavity artery* (Pl. III, fig. 23; C.'C.'A.).

The *posterior cerebral arteries* (Pl. III, figs. 23 and 25; P.-Cer.A.) come off from the encephalic artery at right angles to

the anterior cerebral artery; they run ventro-laterad across the optic nerves, the cerebral hemispheres, the III and IV nerves. Shortly after crossing the IV nerve each vessel makes a sharp curve at nearly right angles; then passing caudad between the IV nerve and the roots of the V and VII, parallel with, but inside of the corresponding vein, they give off several superficial branches to the mesencephal (optic lobes) and hypoaria (inferior lobes). The outer layer of the former contains a mass of blood vessels. Close to the posterior end of the hypoaria each posterior cerebral artery bends inward with the III nerve and the corresponding vein, between the mesencephal, hypoaria and crura cerebri, and when the saccus vasculosus is reached this vessel divides into an anterior and a posterior branch. The anterior branch unites with the corresponding vessel from the opposite side in the median line above the anterior part of the saccus vasculosus to form the *mesencephalic artery* (Pl. III, fig. 25; Me.A.), which passes cephalad a short distance in the crura; then turning dorsad, penetrates the floor of the mesencephal directly in front of the valvula cerebelli (volvula of other authors), and here sends out a lateral branch along the dorsal surface of each torus semicircularis. In like manner the posterior forks of the posterior cerebral arteries unite in the median line above the posterior end of the saccus vasculosus, and the vessel thus formed continues caudad along the ventral surface of the oblongata as the *myelonal* or *oblongata artery* (Pl. III, figs. 23 and 25; My.A.). Along its short course several branches are given off to the oblongata and one to the auditory region. The first vessel for the oblongata is given off near the source of the myelonal artery and passes up through the crura to the metacœle (IV ventricle), where it branches out caudad in the dorsal part of the crura. The second branch comes up through the ventral fissure of the oblongata in the neighborhood of the facialis lobe and breaks up similarly to the first branch. The third branch, which is much larger, is the *auditory artery* (Pl. III, figs. 23, 23a, 24 and 25; Aud.A.). Its course is obliquely laterad across the oblongata, but before coming out from under the roots of the VII nerve, sends up a dorsal branch, the *third cranial cavity artery* (Pl. III, figs. 23

and 23a; C."C."A."), which passes between the ventral lateralis and the motor roots of the VII nerve to the roof of the skull, supplying the adipose tissue surrounding the brain and the semicircular canals. Emerging from beneath the motor root of the VII nerve, the auditory artery divides into an anterior and a posterior auditory artery. The *anterior auditory artery* (Pl. III, figs. 23a and 25; A.Aud.A.) follows along the anterior surface of the ramulus acusticus ampullæ anterioris; passing beneath the anterior ampulla to which it gives off a branch, it continues on to the external ampulla and its semicircular canal. The *posterior auditory artery* (Pl. III, figs. 23, 23a and 25; P.Aud.A.), which at first passes caudad under the ramulus acusticus ampullæ anterioris and the ramulus acusticus sacculi, comes up through the center of the latter and passes along in front of the ramulus acusticus ampullæ posterioris, to supply the posterior ampulla, its semicircular canal, and the utriculus. The myelonal artery terminates in 2 forks on the ventral surface of the myel, in the region of the first spinal nerves. These branches usually anastomose with a branch of the first neural or vertebral arteries, which having their origin from the subclavians make them analogous to the anastomosis of the basilar and vertebral arteries of mammals, of which a more detailed description will be given under the subclavian arteries. At the point where the posterior cerebral artery bends to penetrate the mesencephalon it gives off, caudad, the *cerebellum artery* (Pl. III, figs. 23 and 24; Cer.A.). This vessel continues parallel, but above the IV nerve, ventrad to the optic lobes, and laterad to the crus. In its caudal course it gradually rises higher on the crus, until in the region of the posterior end of the optic lobes it gets to lie between the optic lobes and the valvula cerebelli. A little behind the origin of the IV nerve and the posterior end of the optic lobes this vessel penetrates the dorso-lateral wall of the valvula cerebelli at the point where the molecular layer of the valvula unites with the corresponding layer of the cerebellum. Its course is then caudad a little to one side of the median line, gradually exhausting itself in the granular layer of the cerebellum.

The fourth and smallest vessel to be given off from the en-

cephalic artery is the *infundibular artery* (Pl. III, fig. 25; Inf.-A.). This vessel, which is given off caudad to the hypophysis and infundibulum, sometimes arises from either of the posterior cerebral arteries close to their origin from the encephalic artery.

Orbito-nasal Arteries (Pls. I, II and III, figs. 1, 5, 13, 17 and 18; O:N.A.). — These vessels which are the cephalic branches of the internal carotid arteries, pass forward along the dorso-lateral surface of the parasphenoid. While still within the eye-muscle canal each orbito-nasal artery runs below the recti muscles, giving off several small branches to the superior, inferior, and internal recti muscles. Shortly after reaching the orbit, what I have designated as the *rectus artery* (Pl. II, fig. 13; Rec.A.) arises between the internal and the inferior recti muscles, giving off at first a small branch to the outer surface of the internal rectus muscle; then dividing, one branch continues caudad between the external and internal recti muscles; while the other branch curves laterad a short distance and in turn bifurcates, one branch going dorsad to the superior rectus muscle, and the other to the inferior rectus muscle. The main orbito-nasal trunk, continuing cephalad, passes behind the internal rectus muscle to which it sends several vessels; and in the anterior part of the orbit passes between, but laterad to the oblique muscles, giving off a dorsal branch to the superior oblique muscle, and in the specimen from which fig. 13 was drawn, 2 ventral branches for the inferior oblique muscle. As has already been mentioned, the blood supply for the external rectus muscle comes largely from the iris artery, which is a branch of the external carotid artery. Together with the orbito-nasal vein and the olfactory nerve, the orbito-nasal artery passes out of the orbit through the olfactory foramen in the prefrontal bone. In passing through this foramen and cephalad of it, the vein lies mesad of the nerve, and the artery lies ventrad to both vein and nerve. Soon after leaving the orbit the orbito-nasal artery gives off at least 2 dorso-cephalic vessels, the *nasal sac arteries* (Pl. III, figs. 17 and 18; N.S.A.₍₁₎). These small vessels at first pass behind and above the olfactory nerve to supply the dorsal radial filaments

of the nasal sac. They penetrate the base of the filaments with branches of the olfactory nerve, and running through the inner connective tissue layer send off branches into the secondary or branching filaments. The main orbito-nasal trunk after passing behind the nasal sac with the corresponding vein and the olfactory nerve divides into a cephalic and a ventral branch. The smaller cephalic branch, crossing behind the orbito-nasal vein, proceeds above it, and becomes the *maxilla artery* (Pls. I and III, figs. 1, 17 and 18; Max.A.₍₁₎). This artery in turn also breaks up into 2 vessels; a dorsal one, which penetrates the premaxilla; and a ventral one, which runs along the posterior surface of the premaxilla. The larger ventral branch is the *posterior maxilla artery* (Pls. I and III, figs. 1, 17 and 18; Max.A.₍₂₎); at the ventral edge of the nasal sac it sends a branch inward to the palatine arch; and directly below this branch at least 2 *ventral nasal sac arteries* (Pl. III, fig. 17; N.S.A.₍₂₎) are given off dorsad, which supply the ventral filaments in a like manner to dorsal nasal sac arteries. Then anastomosing with the much smaller facialis-maxillaris artery it runs along and breaks up on the outer surface of the adductor mandibulæ muscle, immediately behind the maxilla.

(c) *Summary of the Carotids*. — Parker has well said (60, P. 653), that: "The application of the name 'carotid' to the cephalic arteries of fishes must of course be taken to imply nothing more than a general correspondence with the similarly named vessels in the higher Vertebrata." For example, his anterior carotid (internal carotid) in *Mustelus* (60, fig. 6), and the similar artery in *Hydrolagus*, *Chimæra* (Pl. III, fig. 26; I.Car.A.), are almost analogous to the ophthalmic artery of *Ophiodon* (Pl. I, figs. 1 and 5; Oph.A) provided that it anastomosed with the orbito-nasal artery with which it comes in such close contact. In the same connection, Parker proposes to substitute the names anterior and posterior carotids for the internal and external carotids. This substitution may seem advisable in the Selachians, where the carotids at first occupy a distinctly anterior and posterior position; but in the case of the Teleosts that I have examined the vessel which has been designated as the internal carotid has a distinctly profundus course, and the external carotid

a superficial one. Even though the cephalic portion of the internal carotid crosses the tract of the external carotid and a branch of one anastomoses with a branch of the other, still, in the main, the internal carotid supplies the region of the internal carotids of the Mammalia. It certainly extends no farther cephalad than the external carotids. For these reasons, in *Ophiodon*, it seems advisable to retain the names internal and external.

4. *Opercular and Dorsal Branchial Muscle Arteries.*

These vessels are 2 very constant arteries, which arise from the dorsal part of the second efferent branchial artery.

Of the 2, the *opercular artery* (Pl. I, fig. 1; Op.A.) is the most dorsal and cephalic vessel. It arises from the anterior surface of the second efferent branchial artery near its point of union with the first efferent branchial artery; its course is first cephalad for a short distance, passing over the second obliquus dorsalis muscle, to which it gives a branch; then curving dorsad, sends off a cephalic branch, which supplies the first internal branchial levator muscle (*Levatores arcuum branchialium interni* of Vetter) and the first obliquus dorsalis muscle; and a little farther up, a third artery is given off to the 4 outer branchial levator muscles (*Levatores arcuum branchialium externi* of Vetter). Then continuing dorsad, laterad to the first efferent branchial artery and jugular vein, it sends off a caudal branch to the levator operculi muscle of Vetter, and when the level of the opercular is reached, terminates by running ventrad along the inner surface of this bone.

The vessel, which is designated as the *dorsal branchial muscle artery* (Pl. I, fig. 1; Br.M.A.), but which supplies fewer branchial muscles than the one designated as the opercular artery, arises from the posterior surface of the second efferent branchial artery directly below the opercular artery. Its course is caudad, passing behind the second internal branchial levator muscle, and over the third and fourth obliqui dorsales muscles, it sends off a branch to each. Then after crossing over the fourth efferent branchial artery it curves ventrad, supplying the occipito-clavicularis muscle, the pharynx, and the dorsal part of the pharyngo-clavicularis internus muscle.

5. *Subclavian Arteries.*

The *subclavian arteries* (Pls. I and II, figs. 1, 5, 14 and 16; Sub.A.), usually,¹ have their origin in a single trunk from the *common chamber* (fig. 5, C.C.). This *common subclavian trunk* (Pl. I, fig. 5) arises above and between the dorsal aorta and the cœliaco-mesenteric artery. For a short distance it runs parallel to the aorta and the cœliaco-mesenteric artery, and then branches at nearly right angles; the right subclavian passing obliquely above the cœliaco-mesenteric artery, the right dorsal branchial retractor muscle, and the right head kidney to the right pectoral fin; while the left subclavian passes between the aorta and the cœliaco-mesenteric artery, above the left dorsal branchial retractor muscle and left head kidney to the left pectoral fin.

After crossing the head kidney the course of each subclavian is ventrad, passing with the combined trunk of the first and second spinal nerves across the outer surface of the head kidney and cardinal vein to the inner surface of the pectoral fin. In the region of the dorso-lateral edge of the head kidney the subclavian gives off the *first neural artery* (Pls. I and II, figs. 1 and 16; Neu.A.₍₁₎), which is somewhat analogous to the vertebral artery in mammals. This vessel runs obliquely dorsad in front of the combined trunk of the first and second spinal nerves, and then passes over the second and first epibranchial arteries, but behind the thymus gland. When the atlas is reached it gives off the *first spinal* or *myelon artery* (Pl. II, fig. 16; Sp.'A.'), which enters a foramen in the exoccipital and usually anastomoses with the myelonal artery. The main stem, however, continues dorsad, terminating in a cephalic, and a dorsal branch. The cephalic branch supplies the trapezius muscle and sends a branch ventrad, which probably supplies the thymus gland. This small vessel I have been able to trace to the thymus, but never have seen it penetrate the gland. Strange to say the arterial supply for the thymus is more difficult to trace than the venous system. The dorsal branch of the first neural artery is destined to supply the superficial, the levator, and the depressor muscles of the first dorsal

¹ For exception see page 45.

spine; and in the specimen from which fig. 16 was drawn, the levator muscle of the second dorsal spine, as well as sending up a branch behind the first dorsal spine.

After giving off the first neural artery the subclavian might be designated as the brachial artery as in mammals, but it seems hardly advisable to press such homologies. Emerging from the head kidney the subclavian passes ventrad along the inner anterior surface of the pectoral superficial adductor muscle; and when the pectoral profundus adductor muscle is reached, a branch is given off to the superficial muscle; then bifurcating, forms what I have designated as the external and internal subclavians.¹ The *internal subclavian artery* (Pl. II, fig. 14; I.Sub.A.) for a short distance continues along the inner cephalic edge of the superficial adductor muscle; then divides into a *superficial internal subclavian artery* (Pl. II, fig. 14; I.Sub.A.₍₁₎), which after giving off a few branches to the superficial adductor muscle continues obliquely ventrad along the inner surface of the profundus adductor muscle; and a *profundus internal subclavian artery* (Pl. II, fig. 14; I.Sub.A.₍₂₎), which immediately penetrates both superficial and profundus adductor muscles and runs obliquely ventrad between the profundus muscle and the scapula, giving off several branches to the former. In the neighborhood of the most dorsal pectoral ray this vessel divides into a brachial ossicle artery and a pectoral fin artery. The brachial ossicle artery crosses these bones in its ventral course just back of the pectoral rays, and exhausts itself by giving off vessels to the distal part of the profundus muscle and by sending off branches between the ossicles to the profundus muscle on the outside of the shoulder-girdle. While the pectoral fin artery penetrates the basal canal (see note, page 50) between the first, or most dorsal, and the second rays, and continuing ventrad in this canal anastomoses with the hypobranchial artery. Throughout its entire course it gives off a branch to the central canal of each ray, which soon divides, one branch continuing along the dorsal side of the cavity and the other along the ventral side. The *external subclavian artery* (Pl. II, fig. 14; E.Sub.A.) immediately passes

¹Perhaps external and internal pectoral arteries would be better names.

through the scapula foramen with the external subclavian vein and a branch of the first and second spinal nerves, and then runs obliquely ventrad between the superficial and profundus abductor muscles, giving off several branches to each.

6. *Cœliaco-Mesenteric Artery.*

The *cœliaco-mesenteric artery* (Pl. I, figs. 1 and 5; Cœ-Mes.A.), which is destined to supply the entire viscera with the exception of the kidney, urinary-bladder, and reproductive organs, is in itself a rather short vessel. With the subclavian it has its source in the *common chamber* (Pl. I, fig. 5; C.C.) beneath and to the right of the aorta and subclavians. It pursues a ventro-caudal course, and passing between the inner side of the right fork of the kidney and the right dorsal branchial retractor muscle enters the thoracic cavity, where it soon divides into the cœliac and mesenteric trunks.

(a) *Cœliac Artery* (Pl. I, figs. 1, 6 and 11; Cœ.A.).—This large vessel for a short distance, runs parallel, but cephalad to the mesenteric artery, then curving around under the stomach, supplies the liver, ventral part of the stomach, pyloric cæca, and a part of the posterior end of the intestine.

The first branch to be given off from the cœliac is the *left hepatic artery* (Pl. I, figs. 6 and 11; L.Hep.A.). It leaves the cœliac under the stomach and breaks up into as many branches as there are terminal branches of the left portal vein. These branches are somewhat irregular, but the first and most cephalic one accompanies terminal branch (a) of the left portal vein. Usually this branch is the source of the *posterior gall-bladder artery* (Pl. I, fig. 11; P.G.Bl.A.), which runs along the dorsal surface of the gall-bladder and anastomoses with the anterior gall-bladder artery, which is a branch of the right hepatic artery (a branch of the mesenteric artery). Both gall-bladder arteries break up into a minute capillary system on the surface of the gall-bladder. A minor posterior gall-bladder artery is often given off to the ventral surface of the gall-bladder (see fig. 11). The second branch of the left hepatic artery accompanies terminal branch (b) of the left portal vein

and the remaining branches follow terminal branches (*c*), (*d*) and (*e*). Ordinarily 1 or 2 branches from the last mentioned arteries follow along in the gastro-hepatic omentum to supply the ventral portion of the stomach. All of the branches of the left hepatic artery follow their corresponding venous trunks to their terminal endings in the substance of the liver. The left hepatic artery furnishes the principal arterial supply for the liver, but in some specimens an additional *posterior* or *minor left hepatic artery* (Pl. I, fig. 11; L.Hep.A.₍₁₎) arises from the cœliac a little farther caudad than the main left hepatic artery and anastomoses with the posterior branches of the left hepatic vessel. Beside the left hepatic vessels there is also the right hepatic artery for the small right lobe of the liver, which will be described further on under the mesenteric artery.

Continuing caudad, parallel, but to the right of the left portal vein, the cœliac artery divides directly in front of the pylorus into a right and left pyloric cæca artery. One of these forks (usually the right) is always considerably longer than the other. The *right pyloric cæca artery* (Pl. I, figs. 1 and 6; R.Cæ.A.) passes at least two-thirds around the pylorus, inside of the pyloric cæca vein a little above the cæca, and in its course gives off at least 3 branches to the cæca. Within the cæca the larger vessels run in the muscular coats and break up into a capillary network in the connective tissue layer of the crypts as in the intestine. One branch of the right pyloric cæca artery is sent off to the pylorus and 2 rather large posterior gastric arteries are given off to the posterior or cardiac portion of the stomach. From the *right posterior gastric artery* (fig. 1; R.P.Gas.A.) one or more branches run along in the peritoneal fold over the cæca to anastomose with the intestinal branch of the mesenteric artery. The left pyloric cæca artery, which is usually much smaller than the right, pursues a similar course on the left side of the pylorus, giving off 2 or 3 branches to the cæca and one to the pylorus. When this is the smaller of the 2 cæca arteries, no branches are given off from it to the posterior end of the stomach, however, only in about one case in 10 is the left pyloric cæca artery larger than the right.

Quite an important vessel arises from the right side of the cœliac artery shortly before it separates to form the pyloric cæca arteries, or sometimes it may arise from the right pyloric cæca artery; it is the vessel designated as *intestinal artery*₍₂₎ (Pl. I, figs. 1, 6 and 11; Int.A.₍₂₎), which strikes the intestine about mid-way between the pylorus and the rectum. For a short distance it runs along, inclosed in adipose tissue, just dorsad of the intestine, and crossing over to the ventral side of the intestine, exchanges places with intestinal artery₍₁₎. This vessel is distinctly a posterior intestinal artery and usually extends to the rectum. Throughout its entire course it sends off branches to the muscular walls of the intestine, which break up into a capillary network in the connective tissue layer of the crypts. In the region of the liver several small branches from the cœliac are given off to the anterior part of the intestine.

(b) *Mesenteric Artery* (Pl. I, fig. 1; Mes.A.). — This vessel is destined to supply the spleen, the greater part of the stomach, and intestine. Soon after leaving the cœliaco-mesenteric trunk the mesenteric artery gives off the *left gastric artery* (Pl. I, figs. 1 and 6; L.Gas.A.) to the left and ventral side of the stomach. This vessel, which lies above the corresponding vein and left gastric ramus of the vagus nerve, crosses the stomach at right angles, then passing along the left side of the stomach, gives off branches to either side, which soon penetrate the muscular walls and break up into a capillary network in the connective tissue layer of the crypts. The main mesenteric trunk after following the stomach for a short distance bifurcates into the right gastric, and intestinal artery₍₁₎. The *right gastric artery* (fig. 1; R.Gas.A.), which is considerably larger than the left, continues between the right gastric ramus of the vagus nerve and the right gastric vein to the posterior or cardiac portion of the stomach, giving off branches from either side to the muscular walls of the stomach. Close to its origin it sends off a branch to the right (see fig. 1), which crosses the cœliac artery and the right portal vein to a gland-like body (G. fig. 1) situated at the junction of the right gastric and the intestinal veins (in structure this gland is very much like the suprarenal bodies). The *Intestinal artery*⁽¹⁾ (Pl. I, figs. 1 and 6; Int.A.₍₁₎) pur-

sues a general caudal direction. Close to its origin this vessel gives off the *right hepatic artery* (Pl. I, fig. 11; R.Hep.-A.), which supplies the smaller right lobe of the liver. This branch runs along by the side of the right portal vein and midway between its source and the right lobe of the liver sends off the *anterior gall-bladder artery* (Pl. I, fig. 11; A.G.Bl.A.), which breaks up on the anterior surface of the gall-bladder, and as has already been mentioned under the head of the posterior gall-bladder artery, the 2 gall-bladder arteries anastomose on the surface of the bladder. A little farther caudad, the *anterior intestinal* or *duodenum artery* (fig. 1; A.Int.A.), is given off from the intestinal artery to the anterior loop of the intestine. The main intestinal trunk then sends off the rather large *splenic artery* (Pl. I, figs. 1 and 6; Spl.A.), which penetrates the anterior surface of the spleen, together with, but dorsad of the splenic vein. Once inside the spleen, it runs entirely through the organ, branching out in the shape of a fan. The intestinal artery, curving around the dorsal surface of the spleen runs along in adipose tissue, parallel with, but closer to the intestine than the corresponding intestinal vein. This artery varies greatly in length. Usually, however, it continues to the rectum, receiving anastomotic branches from the right posterior gastric artery, and curving around to the opposite or dorsal side of the intestine, anastomoses with the *posterior mesenteric artery* (fig. 1; P.Mes.A.). In several specimens, however, the intestinal artery did not continue much farther caudad than the spleen, and the posterior part of the intestine usually supplied by this vessel received its supply from the right posterior gastric artery and the posterior mesenteric artery. As in the stomach and cæca, the larger vessels run in the longitudinal and circular muscular coats and break up into a network of capillaries in the connective tissue coat.

(c) *Comparisons with Other Genera of the Suborder.*—In different genera, it is within the viscera where most of the variation in the blood vessels occur. This is perhaps in a large measure due to the variation in the shape and location of the various organs and to the presence or absence of certain of them. Of the 3 fishes figured in plate IV, probably the arterial

supply for the viscera of *Scorpaenichthys* is most like *Ophiodon*, and *Sebastodes* most like the ordinary Acanthopterygian fishes.

The origin of the cœliaco-mesenteric trunk is the same for all 4 genera studied, but as regards the branching of the cœliac and especially the mesenteric, there is considerable variation.

Cœliac Artery. — In *Hexagrammos* the cœliac branches off from the cœliaco-mesenteric trunk much further caudad than is the case with the other 3 genera; in fact, the cœliac and the left gastric are given off together. In all 4 genera the cœliac terminates by dividing into the 2 pyloric cæca arteries, but in *Ophiodon* only does a pyloric cæca artery supply the posterior part of the stomach. In *Sebastodes* the *left hepatic arteries* (Pl. IV, fig. 32: L.Hep.A.) arise in a similar manner to the corresponding vessels of *Ophiodon*, except that the posterior left hepatic artery is much larger than in *Ophiodon*; while in *Scorpaenichthys* and *Hexagrammos*, strange to say, the left hepatic arises from the right gastric, but in *Hexagrammos* it comes into such close contact with the cœliac that at first one might be led to believe it arose from the cœliac or at least anastomosed with it. In *Hexagrammos* only does the intestinal artery₍₂₎ arise from the cœliac as in *Ophiodon*; in *Scorpaenichthys* and *Sebastodes* it is a branch from intestinal artery₍₁₎.

Mesenteric Artery. — The right and left gastric arteries respectively are essentially the same in all 4 genera. However, since there are so many variations in the branching of the right gastric, the distribution of intestinal artery₍₁₎, and the additional air-bladder and anterior spermatic arteries in *Sebastodes*, it seems advisable to describe in detail the distribution of the mesenteric artery for each of the above genera.

Mesenteric Artery in Scorpaenichthys (Pl. IV, fig. 29; a fork of Cœ. Mes.A.). — After giving off the left gastric artery, the mesenteric artery separates into the *right gastric artery* (fig. 29, R.Gas.A.) and the intestinal artery₍₁₎ (fig. 29; Int.A.₍₁₎). The former gives off the *left hepatic artery* (figs. 29 and 30; L.-Hep.A.) and the latter follows along the stomach for a short distance, giving off a small branch to a small gland-like body, marked *g*, and the *splenic artery* (Pl. IV, fig. 29; Spl.A.), but before entering the spleen this vessel sends off a *posterior gas-*

tric artery (Pl. IV, fig. 29; P.Gas.A.), which supplies the ventral posterior or cardiac portion of the stomach. The main intestinal trunk crosses the cæca and after passing under the first arm of the ileum sends off *intestinal artery*₍₂₎ (Pl. IV, fig. 29; Int A.₂), which supplies the posterior part of the intestine; while the main intestinal trunk continues caudad, supplying both arms of the ileum. Except from the different points of origin, the *left hepatic artery* (Pl. IV, figs. 29 and 30; L.Hep.A.) coming from the right gastric artery, and the *right hepatic artery* (Pl. IV, figs. 29 and 30; R.Hep.A.) from the left gastric artery, the peripheral distribution of the 2 hepatic arteries is practically the same as in *Ophiodon*. Perhaps it should be mentioned that there is but one left hepatic artery in *Scorpenichthys*.

Mesenteric Artery in Hexagrammos (Pl. IV, fig. 27; Mes.-A.). — As has already been stated, the *left gastric artery* (Pl. IV, fig. 27; L.Gas.A.), which is much shorter than in the other 3 genera, is given off almost directly opposite the celiac artery. This would make it appear as though the coeliaco-mesenteric trunk separated into 3 branches, namely, the celiac, mesenteric and left gastric arteries. The mesenteric artery runs along the stomach for a short distance and divides into the characteristic right gastric and intestinal arteries. As in *Ophiodon* the *right gastric artery* (Pl. IV, fig. 27; R.Gas.A.) follows along the right and upper side of the stomach, but it has, however, exchanged positions with the right gastric vein. In this respect it also differs from *Scorpenichthys* and *Sebastodes*. Close to its source it gives off the *left hepatic artery* (Pl. IV, figs. 27 and 28; L.Hep.A.), which comes into very close contact with the celiac artery and breaks up into 3 branches, which penetrate the liver with terminal branches *a*, *b*, and *c* of the left portal vein. The branch following terminal branch *a* anastomoses with the right hepatic artery in a similar manner to the anastomosing of this branch of the left portal with the right portal vein. As in *Scorpenichthys* there is but one left hepatic artery. The *Intestinal artery*₍₁₎ (Pl. IV, fig. 27; Int.A.₍₁₎) soon after leaving the mesenteric artery sends off the *right hepatic artery* (Pl. IV, fig. 27; R.Hep.A.), which at first runs along the surface of the gall-bladder as the gall-bladder artery, and pene-

trating the liver with the right portal vein, anastomoses with the most anterior branch of the left hepatic artery. By this anastomosis the conditions are somewhat analogous to *Ophiodon*; where the posterior gall-bladder artery, which arises from the most anterior branch of the left hepatic artery, anastomoses on the surface of the gall-bladder with the anterior gall-bladder artery, which is a branch from the right hepatic artery. The intestinal artery₍₁₎ then crosses above the anterior or duodenum portion of the intestine and intestinal vein₍₂₎, gives off several branches to the intestine and then continuing caudad with the intestinal vein₍₁₎, between the arms of the iliac loop, extends past the loop to supply the rectum. When near the end of the loop the *splenic artery* (Pl. IV, fig. 27; Spl.A.) is given off to the spleen, which, strange to say, is located on the posterior end of the intestine close to the rectum. However, before entering the spleen, the splenic artery sends off a branch to the posterior end of the intestine.

Mesenteric Artery in Sebastodes (Pl. IV, fig. 31; Mes. A.). — In this genus, which is supposed to be less specialized than the above genera, several new features are introduced, among them, a vessel for the air-bladder and 2 for the reproductive organs. After giving off the *left gastric artery* (Pl. IV, fig. 31; L.Gas.A.), which is the principal artery for the stomach, the mesenteric artery bifurcates into its 2 characteristic divisions, namely, the right gastric, and intestinal artery₍₁₎. The *right gastric artery* (fig. 31; R.Gas.A.) in *Sebastodes* is much shorter than in the other 3 genera and gives off several important trunks. The first important branch is the *right anterior spermatic artery* (Pl. IV, fig. 31; R.Sper.A.). Together with the corresponding vein this vessel passes caudad under the air-bladder vessels to supply the right ovary or testis with a large part of its arterial blood, and anastomoses above with the spermatic artery proper (fig. 31; Sper.A.). The second vessel to be given off from the right gastric is the small *right hepatic artery* (Pl. IV, fig. 31; R.Hep.A.). This vessel penetrates the right lobe of the liver with the right portal vein, and often sends off a branch to a gland-like body situated near the right portal vein. Usually the right hepatic artery gives off the *anterior*

gall-bladder artery (Pl. IV, fig. 34; A.G.Bl.A.). In case such a branch is given off it usually supplies the above mentioned gland (see fig. 34; G.) The third branch of the right gastric is the *air-bladder retia mirabilia* or *anterior air-bladder artery* (Pl. IV, fig. 31; A.Bl.A.); it crosses above intestinal artery₍₁₎ and the right anterior spermatic vessels, just in front of the right mesenteric and the anterior air-bladder veins. Penetrating the thick ventral muscular walls of the air-bladder it breaks up internally into small branches, which in turn break up into minute parallel arterial capillaries, that become continuous distad with parallel venous capillaries, and which are afterward collected into small veins that empty into the air-bladder retia mirabilia vein. This sort of a horseshoe-shaped mass of capillaries on the floor of the air-bladder is known as the retia mirabilia or vaso-ganglion of the air-bladder; it is a vaso-ganglion of the bipolar type. This broad expanse of capillaries affords a good opportunity for the exchange of gases from the blood to the bladder and conversely. The fourth and last branch to be given off from the right gastric artery is the *left anterior spermatic artery* (Pl. IV, fig. 31; L.Sper.A.). This vessel pursues a similar course to the right anterior spermatic artery, following parallel with the corresponding vein it helps supply the left ovary or testis and anastomoses posteriorly with the spermatic artery proper. *Intestinal artery*₍₁₎ (Pl. IV, fig. 31; Int.A.₁) pursues a general caudal course, passing under or rather to the right of all the above mentioned arteries. When in the neighborhood of the spleen it divides; the posterior fork, which is designated as the continuation of the main intestinal artery₍₁₎, passes caudad to supply the posterior end of the intestine; while the anterior fork soon divides into the splenic artery and what I have designated as intestinal artery₍₂₎. *Intestinal artery*₍₂₎ (Pl. IV, fig. 31; Int.A.₂) is so named because it runs parallel with a vein, which has the same terminus as intestinal vein₍₂₎ of *Ophiodon*, but it is hardly probable that this artery is homologous with intestinal artery₍₂₎ of *Ophiodon*. This artery separates into an anterior branch, which supplies the anterior part of the intestine or duodenum and a posterior branch, which supplies the iliac part of the intestine. In some

specimens where there was no anterior gall-bladder artery, as is shown in fig. 33, there is a *posterior gall-bladder artery* (fig. 33; P.G.Bl.A.) arising from the intestinal artery₍₂₎, which in addition to supplying the gall-bladder is continued caudad to supply a portion of the ileum. The *splenic artery* (Pl. IV, fig. 31; Spl.A.) penetrates the spleen with the splenic vein, but before entering it, gives off a *posterior gastric artery* (Pl. IV, fig. 31; P.Gas.A.), which passes beneath the spleen to the ventro-posterior end of the stomach; and like the posterior gastric artery of *Ophiodon*, which, however, has a different origin, coming from the right pyloric cæca artery, it sends off a branch to the posterior portion of the intestine.

7. *Dorsal Aorta.*

This vessel (Pl. I, figs. 1, 5, and 10 D.Ao.), which is the largest artery in a fish, arises as the most dorsal trunk from the *common chamber* (Pl. I, fig. 5; C.C.) and continues caudad in a median line directly below the vertebral column to the last caudal vertebra. At first the dorsal aorta runs between the 2 anterior lobes of the kidney, above and between the dorsal branchial retractor muscles, and when the posterior unpaired part of the kidney is reached, runs along in its dorsal groove. After leaving the kidney and the body cavity, the aorta is known as the *caudal artery* (Pl. I, figs. 1, 7, 8, 9 and 10; Cau.A.). It penetrates the hæmal canal of the first caudal vertebra with the caudal vein and continues in the hæmal canal above the vein until the last caudal vertebra is reached, where at about the middle of the last centrum it separates into a right and a left caudal artery. The *left caudal artery* (Pl. I, fig. 8; L.Cau.A.) is much the shorter; it sends a branch upward in front of the urostyle, which supplies both profundus and superficial muscles. The much larger *right caudal artery* (Pl. I, figs. 1 and 8; R.Cau.A.) following along the outer margin of the last centrum and after giving off a branch in front of the urostyle similar to the left caudal artery, continues caudad in a median line between the 2 hypural bones, parallel with the longitudinal hæmal lymphatic vessel, giving off branches from both sides to the profundus

muscle of the caudal fin. When the caudal fin is reached this artery bifurcates into a dorsal and a ventral vessel, which run dorsad or ventrad in the basal canal of the caudal rays, directly in front of the corresponding lymphatic and venous vessels. The central canal of each ray receives a branch, which at first runs in the center of the cavity and then divides, the 2 forks continuing caudad along the dorsal and ventral sides of the canal.

Throughout its entire course the dorsal aorta gives off branches to the great lateral muscles, the spinal cord, and the rays of the unpaired fins; beside supplying the kidney, reproductive organs and the rectum.

(a) *Arteries Supplying the Great Lateral Muscle, Cord, etc.*—Perhaps the most typical place first to take up these vessels is in the region of the caudal vertebræ. In fig. 1 such a region is shown just posterior to the kidney. The common arrangement consists of a dorsal or neural artery and a ventral or hæmal artery, which usually supply the region covered by 2 myotomes; sometimes, however, one of these arteries may supply 3 or even 4 myotomes.

The dorsal or *neural arteries* (Pl. I, fig. 1; Neu.A.) in this region arise from the dorsal side of the caudal artery. Emerging from the anterior surface of the hæmal arch each neural artery curves around the anterior end of either the right or left side of the centrum. Here a branch, the *median lateral artery* (fig. 1; M.Lat.A.) is given off to the great lateral muscle. A second branch, the *spinal* or *myelon artery*, penetrates the spinal foramen. The neural artery then curves around in front of the neural spine and continues dorsad between the spine and the neural lymphatic vessel. Near the end of the spine the *dorsal lateral artery* (fig. 1; D.Lat.A.) is given off to the great lateral muscle. Then passing cephalad the neural artery supplies the levator and depressor muscles of this and the preceding dorsal rays, as well as supplying the superficial muscles and sending up a branch behind this and the preceding dorsal rays. This description will hold for all the neural arteries from the head to the tail, except that the most cephalic one arises from a different source (see under Subclavian artery),

and the second and third neural arteries (fig. 5; Neu.A._{2 and 3}) supply the dorsal branchial retractor muscles and the anterior forks of the kidney in addition to the musculature already described.

Hæmal Arteries (fig. 1; Hæ.A.).—These vessels arise from the ventral side of the caudal artery, a little behind the corresponding neural arteries, and crossing over the caudal vein run ventrad between the hæmal spines and the hæmal lymphatic vessels. Near the end of the spines they give off the *ventral lateral arteries* (fig. 1; V.Lat.A.) for the great lateral muscle, then curving cephalad, break up among the superficial and profundus anal ray muscles in like manner to the neural arteries in the dorsal fin musculature. The homologous intercostal arteries of the visceral body wall have their origin in a common vessel, which supplies also the kidney and often the reproductive organs.

(b) *Renal and Spermatic Arteries*.—As has just been stated, the renal and spermatic arteries as well as the intercostals often have their source in one and the same artery, which is probably homologous with the hæmal arteries of the caudal region. For convenience we will speak of these common trunks in the region of the anterior part of the kidney as the intercostal arteries and in the region of the posterior part of the kidney, where the main branch goes to the reproductive organs, as the spermatic arteries.

Intercostal Arteries (fig. 1; Intc.A.).—These vessels arise from the ventral side of the aorta, in the region of each alternate vertebra, and passing across the lateral surface of either side of the kidney, they give off several *renal arteries* (fig. 1; Ren.A.) for the kidney; but the main trunks or intercostal arteries proper continue ventrad between 2 myotomes and anastomose with branches from the ventral artery, the so-called ventral intercostal arteries.

Spermatic Arteries (Pl. I, figs. 1 and 10; Sper.A.).—In both male and female there are at least 3 spermatic arteries, which always cross the left side of the kidney, giving off several renal arteries and one intercostal artery before leaving the kidney for the reproductive organs. These arteries increase

in size as these organs increase in size toward the breeding season, which is in January at Monterey Bay. In the female these vessels branch before reaching the ovaries and these branches spread out over the outer and inner surfaces of the ovaries; while in the male these branches penetrate directly into the testes. No common spermatic artery is formed in either male or female by the anastomosis of these branches, to pass between and parallel with the reproductive organs, as is the case with the veins. The *anterior spermatic artery* (Pl. I, figs. 1 and 10; Sper.A.₁) arises from the ventral surface of the aorta and passing obliquely ventrad across the left side of the kidney, gives off 1 or 2 renal arteries for the kidney and an intercostal artery, which passes ventrad between the 2 adjacent myotomes; the main spermatic trunk also continues ventrad to break up on the anterior surface of the ovaries or to penetrate the testes. The *second spermatic artery* (Pl. I, figs. 1 and 10; Sper.A.₂) is given off from the aorta, about the distance of 2 vertebræ from the first spermatic artery, and in like manner sends off renal and intercostal arteries for the kidney and body-wall; while the main trunk supplies the middle portion of the ovaries or testes. The *third or posterior spermatic artery* (Pl. I, figs. 1 and 10; Sper.A.₃) is much the largest; in addition to supplying the ordinary renal and intercostal arteries, it gives off from 1 to 3 *suprarenal arteries* (Pl. I, figs. 1 and 10; Sr.A.) for that gland. In fig. 1 the third spermatic artery passed in front of the gland and only one artery was observed to enter the gland; while in fig. 10 the main artery passed behind the gland and at least 3 arteries were seen to penetrate it. In the specimen from which fig. 1 was drawn the *posterior mesenteric artery* (fig. 1; P.Mes.A.) arises from the last spermatic artery, passing behind the posterior mesenteric vein, it continues ventrad with it between the ovaries to supply the rectum and anastomoses with intestinal artery₍₁₎; while in the specimen from which fig. 10 was drawn the posterior mesenteric artery was given off much further dorsad and at first entered the kidney as a renal artery; then passing ventrad between the testes with the corresponding vein, supplied the rectum, but did not anastomose with intestinal artery₍₁₎; while in still other specimens the pos-

terior mesenteric artery was not observed; possibly, however, it was not injected. The posterior spermatic proper breaks up into numerous branches, which run along the posterior surface of the ovaries or penetrate the testes. The most posterior branch of the third spermatic artery is destined to supply the common oviduct or spermduct and sends off the *anterior urinary bladder artery* to the bladder. The *posterior urinary bladder artery* (Pl. I, figs. 1 and 10; Ur.B.A.) or the urinary bladder artery proper arises from the aorta directly behind the kidney, and in the specimen from which fig. 10 was drawn, a renal artery was given off to the kidney. In addition to supplying the urinary bladder this vessel usually sends off a branch to the great lateral muscle. It is probably a modified hæmal artery.

(c) *Comparisons of Hexagrammos, Scorpænichthys and Sebastodes.*—In these 3 different genera there is not nearly as much variation in the distribution of the dorsal aorta as there is in the distribution of the cardinal veins. *Hexagrammos* is identical with *Ophiodon*. In *Scorpænichthys* there are only 2 spermatic arteries, but what has been designated as the *urinary bladder artery* (Pl. IV, fig. 29; Ur.Bl.A.) arises much farther cephalad than the corresponding vessel in *Ophiodon*, and may in part be homologous to the posterior spermatic artery of *Ophiodon*, except that it does not supply the reproductive organs; running along the dorso-caudal surface of the kidney it passes between the suprarenal bodies and sends off a branch to each of them. (It will be noticed that the suprarenal glands are located much further dorsad on the kidney than they are in *Ophiodon*.) Then passing ventrad the urinary bladder artery passes behind the posterior mesenteric vein to supply the posterior part of the urinary bladder, and usually it is continued still farther ventrad to supply the rectum. In *Sebastodes* several changes are introduced, which are caused by the presence of the air-bladder and anterior spermatic arteries. Where the anterior spermatic artery is given off in *Ophiodon*, *Hexagrammos* and *Scorpænichthys* a similar vessel arises from the aorta in *Sebastodes*; this vessel, however, is destined to supply the air-bladder and is designated as the *posterior air-bladder artery* (Pl. IV, fig. 31; P.A.Bl.A.). In passing over the left side of the kidney it gives off several

renal arteries and finally breaks up on the posterior end of the air-bladder. The single *spermatic artery* (Pl. IV, fig. 31; Sper.-A.), which performs part of the function of the urinary bladder artery of *Ophiodon* is given off from the aorta immediately in front of the point where the caudal vein penetrates the kidney. Near its source it sends off an intercostal artery (see fig. 31). It then follows along the posterior margin of the kidney, to the right of the caudal vein, and passing between the suprarenal bodies,¹ supplies each with a branch. The spermatic artery then continues ventrad between the kidney and the reproductive organs, gives off caudad the *urinary bladder artery* (fig. 31, Ur.Bl.A.), which is the only artery observed for the bladder. When the genital organs are reached, the spermatic artery anastomoses with the 2 anterior spermatic arteries already described under the head of the mesenteric artery.

VII. PERIPHERAL DISTRIBUTION OF THE VEINS.

The veins in general follow their corresponding arterial trunks, but not so closely as they do the nerves. There is much less literature on the veins than on the arteries. In Selachians where it is so much more difficult to inject the veins this is not strange, but with the Teleosts no more difficulty is experienced in injecting the veins. Generally the whole venous system can be satisfactorily injected from one point. (See under paragraph on technique).

1. *Jugular Veins.*

These large sinus-like vessels (Pls. I and II, figs. 1, 5, 15 and 16; J.V.), which are much longer than the corresponding common carotid arteries, arise in front of the prootic process from 3 principal trunks (see fig. 15). The external jugulars, coming from the facial region; the internal jugulars, coming from the eye, eye-muscles, and brain; and the orbito-nasal vein. Each jugular immediately enters the foramen formed by the prootic process and in its course through this foramen it is a rather small vessel lying directly above the external carotid

¹The suprarenal bodies are situated further caudad on the kidney than in *Ophiodon*.

artery, but upon emerging from this foramen rapidly increases in caliber. Then continuing caudad it passes over the efferent branchial arteries, and when the head kidney is reached follows along its ventral surface and terminates by anastomosing with the corresponding cardinal vein to form the great precaval trunk. Throughout its short course it receives numerous branches from the dorsal branchial muscles and the head kidney, which will be described in detail after considering the 3 principal trunks which go to make up the jugular vein.

(a) *External Jugular Veins* (Pls. I and II, figs. 1, 5 and 15; Ex.J.V.).—Of the 3 vessels which unite to form the jugular vein this is the largest. It also arises from 3 rather large trunks, the largest of which is the *facialis-mandibularis vein* (Pls. I and II, figs. 1 and 12; F.Man.V.). This vessel has its source in the anterior part of the lower jaw from the *genio-hyoideus vein* (Pls. I and II, figs. 1 and 12; Ghs.V.), which runs along the ventral surface of that muscle just outside of the corresponding artery, which is a branch of the left hyoidean artery. The *facialis-mandibularis vein* at first passes along the inner side of the dentary bone, receiving numerous branches from the mandibular portion of the adductor mandibulæ muscle. Shortly before leaving the articular bone it receives a large secondary mandibular vein, coming from the ventral side of the muscle, and a posterior branch coming from the inner side of the quadrate bone. The *facialis-mandibularis vein* then makes a dorsal bend; leaving the corresponding artery it follows up behind the ramus mandibularis V, or ramus maxillaris inferior of other authors, between the superficial and profundus portions of the adductor mandibulæ muscle, receiving several rather large branches from each. At the level of the levator arcus palatini muscle it receives, from the rear, the hyoidean vein.

Hyoidean Veins (Pls. I and II, figs. 1 and 12; Hyo.V.).—These vessels have their origin in the hyohyoideus superior muscles. Each vein runs along in that muscle some little distance ventrad of the hyoidean artery, which follows along on the surface of the arch. The vein receives a branch from the region of each branchiostegal ray and when the end of the arch

is reached it curves cephalad, following along the interhyal, but above the minor hyoidean artery and the ramus hyoideus. When the preopercular is reached the course of this vein is dorsad behind the ramus hyoideus and when a little past the middle of the preopercular, it passes with the nerve to the outer surface of the hyomandibular through a foramen between the hyomandibular and the preopercular. Here it receives a ventral branch from the posterior part of the adductor mandibulæ muscle, which follows along the outer surface of the preopercular. The main stem then leaves the hyoidean ramus and continues obliquely cephalad a little ventrad of the levator arcus palatini and between the superficial and profundus portions of ^{the} adductor mandibulæ, to unite with the facialis-mandibularis vein. The combined trunk proceeds dorsad for a short distance between the ramus mandibularis V and the facial artery to the floor of the orbit; where it receives the facialis-maxillaris vein.

Facialis-maxillaris Veins (Pls. I and III, figs. 1, 17, and 18; F.Max.V.). — Each of these vessels has its origin from a dorsal and a cephalic branch. The larger dorsal branch arises as an anastomotic vein from the orbito-nasal vein (see fig. 18); passing beneath the nasal sac some little distance cephalad of the corresponding artery it receives at the level of the ventral surface of the nasal sac a rather large vein coming from the region of the palatine arch; and then continuing ventrad a short distance the main stem passes under the maxilla artery and unites with the maxilla vein. The *maxilla vein* (Pls. I and III, figs. 1 and 17; Max.V.) has its source in a superficial and a profundus branch from the premaxilla, which unite in the region of the vomer. In its caudal course it receives several branches from the anterior part of the adductor mandibulæ muscle. After uniting with the dorsal branch from the region of the nasal sac the facialis-maxillaris vein proper crosses over the small facialis-maxillaris artery, and continuing caudad between the ramus maxillaris V or ramus maxillaris superior and the facialis-maxillaris artery in the adductor arcus palatini from which it receives several branches, it unites with the combined trunk of the mandibular and hyoidean veins in the posterior part of the orbit to form the external jugular trunk.

The facialis-maxillaris vein is much larger than the corresponding artery. It returns most of the venous blood from the region of the maxilla; while it is the orbito-nasal artery, which furnishes this region with most of its arterial supply.

The external jugular vein (Pls. I and II, figs. 1, 5 and 15; Ex.J.V.) is in itself a rather short trunk. It follows along in front of the truncus infra-orbitalis or truncus buccalis-maxillo-mandibularis and the external carotid artery in the posterior part of the orbit; passing over the hyomandibular bone it unites with the orbito-nasal and internal jugular veins in front of the prootic process.

(b) *Internal Jugular Veins* (Pls. I and II, figs. 1, 13 and 15; In.J.V.). — What has been designated as the internal jugulars return the venous blood from the eye, recti muscles, and the brain. Each of these trunks might be said to have its source from the rectus, ophthalmic, and iris veins (see fig. 15) and at this point of union it also receives or sends off a large sinus-like vessel,¹ which extends caudo-mesad in the eye-muscle canal and anastomoses in the median line with a corresponding sinus-like vessel from the opposite internal jugular vein. This horse-shoe shaped sinus incloses the encephalic artery and receives a posterior branch from each of the external recti muscles. The main internal jugular vein becomes greatly reduced in caliber in passing through what might be called the internal jugular foramen (a foramen between the alisphenoid, prootic, and parasphenoid process, through which pass the internal jugular, the iris artery, and the ciliary nerve). Emerging from this foramen the internal jugular receives the encephalic vein, coming through the cranium through the small encephalic vein foramen (the most cephalic of the 3 foramina in the prootic, through which the encephalic vein and ciliary nerve pass). In front of the prootic process the internal jugular unites with the external jugular at an angle of about 75°. Coming in between these 2 trunks is the orbito-nasal vein, which might almost be said to unite with the internal jugular before it joins the external jugular.

¹ This connecting sinus may be the same as the cross vessel connecting the two Bulbi ophthalmici described by Hyrtl (31, p. 236).

Rectus Vein (Pl. II, figs. 13 and 15; Rec.V.). — This vessel arises from a ventral branch coming from the inferior rectus muscle and a cephalic branch coming from the superior and internal recti muscles. Its course is then dorsad between the optic nerve and the superior rectus muscle, and it unites with the ophthalmic and iris veins to form the internal jugular trunk. The vein from the external rectus muscle empties into the iris vein and will be described more fully in connection with that vessel.

Ophthalmic Veins (Pls. I and II, figs. 1, 5, 13, 15 and 19; Oph.V.). — Each of these veins carries off the venous blood, which has become collected in the *choroid sinus*. This sinus (Pl. III, fig. 19; Chor.S.) is horse-shoe shaped, the anterior arm being much longer than the posterior one. It lies between the silver layer of the choroid and the similar shaped choroid artery, and occupying a large part of the space between the optic nerve and the choroid gland, drains the entire choroid coat and also the ventral portion of the iris. The venous blood from the dorsal part of the iris is returned by the iris vein proper, which will be described later on. The capillaries in the choroid may reach the choroid sinus in either of 2 ways. They may become collected into the *choroid veins* (Pl. III, fig. 21; Chor.V.), which break up into a fine rete mirabile of venous capillaries which run parallel with the arterial rete mirabile capillaries, and these in turn become collected into larger venous vessels that empty into the choroid sinus; or they may reach the choroid sinus directly by what I have designated as the *dorsal choroid vein* or the 2 *ventral choroid veins* (Pl. III, fig. 19; D.Chor.V. and V.Chor.V.), which empty into the anterior and posterior horns respectively. The vein returning the venous blood from the ventral portion of the iris is designated as the *ventral* or *minor iris vein* (Pl. III, fig. 19; Ir.V.₍₁₎). This vessel passes obliquely dorsad in the vascular layer of the choroid, directly cephalad of the ramus ciliaris brevis, and empties into the inner side of the anterior horn of the choroid sinus. No similar artery was observed and it is probable that the arterial supply for the ventral part of the iris comes from the ventral choroid arteries rather than from the iris artery.

The *ophthalmic vein* proper (Pls. I, II and III, figs. 1, 5, 13, 15 and 19; Oph.V.) arises as a sinus-like vessel from the dorsal region of the anterior horn of the choroid sinus, but gradually tapers down into its caudal course, and when immediately ventrad of the optic nerve receives a much smaller branch from the posterior horn. Curving around to the posterior side of the optic nerve it penetrates the silver layer of the choroid and the sclerotic coat. Once outside of the eyeball the ophthalmic vein pursues an oblique dorsal course, and, passing between the superior and external recti muscles it unites with the rectus and iris veins to form the internal jugular.

Iris or Ophthalmic Minor Veins (Pl. II and III, figs. 13, 15 and 19; Ir.V.).—A single iris vein arises from the capillaries in the dorsal part of the iris. Together with the ramus ciliaris longus and the iris artery it passes ventrad a short distance, between the silvery and vascular layers of the choroid (see fig. 19), and then penetrates the silvery layer and the sclerotic coat. After running along the posterior dorsal surface of the eyeball it passes between the superior and external recti muscles, but laterad to the ophthalmic vein. In its caudal course it receives a branch from the external rectus muscle, and finally terminates by uniting with the rectus and ophthalmic veins to form the internal jugular.

Optic or Retina Vein (Pl. III, figs. 19 and 20; Opt.V.).—In the specimen from which figs. 19 and 20 were drawn I noticed a small vein penetrating the sclerotic coat just ventrad of the optic artery. Its connection with the larger vessels had been destroyed before the vein was noticed, and internally the vein was not injected. Several specimens were injected especially to demonstrate this vessel, but in every case this vein failed to become injected. It is probable, however, that this vein follows the course of the optic artery, returning the venous blood from the lens, falciform process, and the retina, and very likely empties into the ophthalmic vein.

As has already been stated in the first paragraph under (*δ*) the internal jugulars are connected with one another by a sinus-like vessel, which crosses the eye-muscle canal. Leaving the eye-muscle canal with the ciliary nerve and the iris artery,

through what was designated as the internal jugular foramen, the internal jugular receives the encephalic vein shortly before uniting with the external jugular and orbito-nasal veins to form the jugular trunk.

Encephalic Veins (Pls. I, II, and III, figs. 1, 15, 23, 24, and 25; Enc.V.).—Each of these veins has its origin from 2 branches, an anterior and a posterior cerebral vein. The former returns the venous blood from the cerebrum, anterior surface of the optic lobes, optic and olfactory nerves; while the latter comes from the cerebellum, optic lobe, hypoaria, infundibulum, and the auditory region.

Anterior Cerebral Vein (Pl. III, figs. 23 to 25; A.Cer.V.).—Cephalad, this vein arises from a small vessel running caudad along the ventro-lateral surface of the olfactory nerve, and receives a branch from the olfactory lobe and one from the optic nerve. About midway between the olfactory and the optic lobes it unites with a much larger vein from the cerebrum. This vessel arises from the inner parts of the cerebrum, and, passing laterad between the cerebrum and the optic nerve, considerably caudad of the corresponding artery, it unites with the small cephalic vein just described. The combined vessel continues caudad a short distance and when opposite the optic lobes receives 2 or more branches coming from the anterior part of the hypoaria, infundibulum, hypophysis, and the anterior surface of the optic lobes. Then curving obliquely cephalad, the anterior cerebral vein proper crosses the III and IV nerves and the posterior cerebral artery to unite with the posterior cerebral vein in forming the encephalic trunk.

Posterior Cerebral Vein (Pl. III, figs. 23 to 25; P.Cer.V.).—This vein has its source from 3 principal branches, namely: the mesencephalic, cerebellum and auditory veins, the 2 latter vessels uniting between the hypoaria and the optic lobes, immediately before the mesencephalic vessel is received. The *auditory vein* (Pl. III, figs. 23, 23a and 25; Aud.V.) arises from branches coming from the utriculus, anterior and external ampullæ. The vein from the posterior ampulla empties into a branch of the posterior encephalic vein, and will be described under that vessel. Continuing cephalad for a short distance

the auditory vein anastomoses with the *cerebellum vein* (Pl. III, figs. 23 and 25; Cer.V.), which arises in and leaves the cerebellum with the cerebellum artery, but below it. In its ventral course it receives a superficial branch from the posterior surface of the optic lobe, and, after uniting with the auditory vein, the combined trunk continues cephalad a short distance between the optic lobe and the hypoaria and ventrad of the posterior cerebral artery before receiving the mesencephalic vein (See fig. 23). The *mesencephalic vein* (Pl. III, figs. 23 to 25; Me.V.) arises from the floor of the mesencephalon (optic lobe) and penetrating ventrad through the crus, passes out between the optic lobe and the hypoaria, in front of the III nerve and mesencephalic artery, then crossing below the nerve and artery it unites with the common vessel formed by the anastomoses of the auditory and cerebellum veins to form the *posterior cerebral vein* (figs. 23 to 25; P.Cer.V.). The course of this vein is cephalad, directly below the posterior cerebral artery, between the optic lobe and hypoaria, and between the trigemino-facial complex and the IV nerve. Uniting with the anterior cerebral vein midway between the cerebrum and the optic lobe it forms the *encephalic vein* (Pls. I, II and III, figs. 1, 15, 23 and 25; Enc.V.), which shortly leaves the IV nerve to follow trigemino-facial complex, and when the facialis portion of the ramus lateralis accessorius is given off the *cranial cavity vein* is received. This vein (Pl. III, fig. 24; C.C.V.) follows along the anterior surface of this nerve and anastomoses caudad with a branch of the posterior encephalic vein, which follows along the posterior surface of the vagus portion of the ramus lateralis accessorius. Hence the venous blood from the adipose tissue of the cranial cavity may reach the jugular vein through the encephalic, or the posterior encephalic vein, or through both. Then leaving the trigemino-facial complex, along the inner surface of the ciliary nerve, the encephalic vein penetrates with it through the most anterior foramen in the prootic, and here empties into the internal jugular just before it unites with the orbitonasal and external jugular in forming the main jugular vein.

(c) *Orbito-nasal Veins* (Pls. I, II and III; figs. 1, 5, 13, 15,

17 and 18; O.N.V.).—Each of these veins has its origin directly behind the maxilla, and, following caudad along the ventral side of the corresponding artery, passes behind the nasal sac, where it receives 2 veins coming from the nasal sac. The smallest and most cephalic one is designated as the *anterior nasal sac vein* (Pl. III, figs. 17 and 18; N.S.V.₍₁₎). In the specimen from which figs. 17 and 18 were drawn this vessel arose from 6 anterior radial veins (see fig. 17). Each of these radial veins runs along the outer or distal edges of the secondary filaments of one of the primary filaments, and from each of these secondary filaments there comes a branch, which receives the capillaries from the inner connective tissue layer of that secondary filament and from that portion of the primary or radial filament. These radial filament veins unite with one another at their bases and finally terminate in the anterior nasal sac vein, which empties into the main orbito-nasal trunk. In like manner the larger *posterior nasal sac vein* (Pl. III, figs. 17 and 18; N.S.V.₍₂₎) arises from 8 posterior radial veins, which take their origin from the secondary filament veins from their respective radial or primary filament. The 2 nasal sac veins are usually distinctly separated as shown in fig. 17, but in a few cases I have noticed that they were connected by a longitudinal vein, thus forming a continuous lateral vein into which all the radial veins were emptied, and from which the 2 nasal sac veins had their source. Between these 2 nasal sac veins, the orbito-nasal vein anastomoses with a branch of the *facialis-maxillaris vein* (see fig. 18). After leaving the nasal sac, the orbito-nasal vein pursues a general caudal course, parallel with, but dorsad of, the orbito-nasal artery and mesad of the olfactory nerve, and enters the orbit through the olfactory foramen in the prefrontal. Once inside the orbit it leaves the olfactory nerve and the orbito-nasal artery to pursue, with the *truncus supra-orbitalis* or *ramus ophthalmicus superficialis* and *profundus*, a sort of dorso-caudal course through the orbit. Passing behind the superior oblique muscle it receives the *inferior oblique vein* (Pl. II, fig. 13; Inf.O.V.), coming up from the outside of that muscle, and the *superior oblique vein* (fig. 13: Sup. O.V.), coming down from the inside of that

muscle. Then continuing caudad, behind the superior rectus muscle and mesad of the truncus supra-orbitalis, it arrives in the posterior dorsal corner of the orbit, where it receives the *sclerotic vein* (Pl. II, fig. 15; Scl.V.). This vessel, which arises from the adipose tissue in the region of the anterior part of the eyeball, runs obliquely caudad across it, mesad of the corresponding nerve and artery. After receiving this branch, the main orbito-nasal vein crosses above the ophthalmic and iris vessels, and following around the eyeball for a short distance, finally comes in between and unites with the external and internal jugulars to form the great jugular vein.

The remarks made under the summary of the carotids apply with equal force to the external and internal jugular veins. These are simply arbitrary names given to the 2 largest veins of the head region, which go to make up the common jugular trunk.

2. *Vessels Emptying Directly into the Jugular or into the Head Kidney.*

a. Veins Emptying into the Kidney. — These veins include the posterior encephalic and the first and second neural veins. They do not empty at once into the jugulars, but penetrate the dorsal surface of the head kidney, break up into smaller vessels, which become reunited forming the renal veins, and these empty into the jugular vein.

Posterior Encephalic Veins (Pls. II and III, figs. 16, 23 to 25; P.Enc.V.).—These veins may be said to concur in part with the first neural or vertebral artery. Each of these veins arises from a superficial capillary network from the dorsal surface of the optic lobes; passing caudad over the cerebellum it receives a superficial branch from it and several from the adipose tissue surrounding the brain and the semi-circular canals; and usually anastomoses with the cranial cavity vein (see fig. 24), which empties into the encephalic vein. After passing over the cerebellum the posterior encephalic vein bends ventrad, following along behind the vagus portion of the ramus lateralis accessorius to its origin from the dorsal root of the vagus, and when the level of the oblongata is reached,

sends off, or receives, a cross vessel from the corresponding vein on the opposite side. This cross vessel receives a branch, coming caudad along the dorsal surface of the oblongata. Whether it returns any of the venous blood from the cerebellum I was unable to determine. In the neighborhood of the origin of the vagus portion of the ramus lateralis accessorius from the dorsal root of the vagus, the posterior encephalic vein receives an anterior branch or *oblongata vein* (Pl. III, fig. 24; Obl.V.), which has its source from the side of the oblongata directly behind the roots of trigemino-facial complex, and shortly receives a branch from the posterior ampulla, then running along the side of the oblongata, passes beneath the IX and X nerves and finally terminates by emptying into the posterior encephalic vein. Following along the dorsal root of the vagus nerve the posterior encephalic vein leaves the brain case through the vagus foramen in the exoccipital, but before leaving the skull the large *myelonal vein* is received from the rear. This vessel (Pl. III, figs. 23 to 25; My.V.) arises on the dorsal surface of the myel as far back as the 9th pair of spinal nerves. After running along on the dorsal surface of the myel for a short distance it separates into a right and a left myelonal vein. Each of these vessels runs along the lateral surface of the myel, passing between the dorsal and ventral roots of the spinal nerves, finally terminating by emptying into the posterior encephalic vein. Along its cephalic course the myelonal vein receives numerous vessels from the myel, and sends across dorsal connecting branches, which unite with the corresponding vein on the opposite side. Although the myelonal vein empties into the posterior encephalic vein, still, not all of its blood reaches the jugular through that vessel, but some of it is carried off by the first 3 *spinal veins* (Pls. II and III, figs. 16 and 24; Sp.V.). These vessels pass out with each alternate pair of spinal nerves, and emptying into the neural veins, which in the case of these anterior veins penetrate the dorsal surface of the head kidney, and here break up into very small veins, which again become collected into vessels that empty into the jugular vein. The posterior encephalic vein is simply a modified spinal vein, which after leaving the skull through

the vagus foramen, follows along behind the nerve and receiving the much smaller neural vein, penetrates the anterior dorsal corner of the head kidney (see fig. 16). Within the head kidney the posterior encephalic or the most anterior neural vein breaks up into very small veins, which again become collected and empty into the jugular vein.

(b) *Veins Emptying Directly into the Jugulars*. — Under this head belong the opercular and the 3 dorsal branchial muscle veins. The latter in addition to draining the branchial muscles receive also the dorsal nutrient branchial veins from the branchial arches. In *Ophiodon* these veins are always present, but vary considerably in their distribution. Perhaps the most common arrangement is shown in fig. 1.

Opercular Veins (fig. 1; Op. V.). — These veins arise on the inner side of the operculars; running dorsad behind the corresponding arteries, they curve ventrad, after leaving the dorsal edge of the operculars, and after receiving a branch from the levator operculi muscles of Vetter, empty into the jugulars a little behind the first dorsal branchial muscle veins.

Dorsal Branchial Muscle Veins (fig. 1; Br.M.V, only the second vein being lettered). — In the specimen from which fig. 1 was drawn, the first of these vessels had its source in, and received its principal supply from, the first *dorsal nutrient branchial vein* (fig. 1; D.N.Br.V.). This vessel arises a little below the dorsal bend, and is at first the most anterior of the 3 vessels in the dorsal part of the first branchial arch. In the arch it receives a *nutrient filament vein* (fig. 2; N.Fil.V.), coming from the inner margin of each filament. When the dorsal bend of the arch is reached, the first dorsal nutrient branchial vein crosses over and continues dorsad behind the first efferent branchial artery. Then following along the outer surface of the first obliquus dorsalis muscle from which it receives a branch, it penetrates with the IX nerve through the first levator arc. branch. internus muscle, and again crossing over the first efferent branchial artery shortly after the carotid is given off, finally empties into the ventral side of the jugular a little cephalad of the opercular vein. The second dorsal branchial muscle vein, in this specimen, takes its source from the union

of the second and third dorsal nutrient branchial veins. The combined vessel thus formed passes dorsad behind the second levator arc. branch. internus muscle, and after receiving a branch from it and another from the second obliquus dorsalis muscle, terminates in the jugular. In this specimen the third and last dorsal branchial muscle vein arose from 2 branches. The most cephalic one is a dorsal nutrient branchial vein from the last branchial arch, and the other has its source from the pharyngo-clavicularis externus, pharynx, and the occipito-clavicularis muscle. The dorsal branchial vessel thus formed passes in a dorso-cephalic direction above the corresponding artery. After crossing the last efferent branchial artery it receives a good-sized branch coming from the last 2 internal branchial levator muscles, and then empties into the jugular directly behind the second dorsal branchial vein, but before emptying into the jugular it receives the *thymus vein* from the rear. This vein (fig. 1; not lettered) runs cephalad along the ventral margin of the gland, receives several branches from it, and shortly before reaching the anterior end of the thymus, curves ventrad; crossing over the posterior encephalic and jugular veins, finally terminates in the third dorsal branchial muscle vein shortly before the latter empties into the jugular. In another specimen from the one figured, the dorsal nutrient vein from the second branchial arch joined the first dorsal branchial muscle vein immediately after it had pierced the first levator arc. branch. internus muscle. The second dorsal branchial muscle vein took its origin from the third dorsal nutrient branchial vein and received branches from the third obliquus dorsalis muscle and the second levator arc. branch. internus muscle; while the third and last dorsal branchial muscle vein had its source from the fourth nutrient branchial vein and a branch coming from the fourth obliquus dorsalis muscle. The thymus vein emptied into the posterior encephalic vein, and the vein from the pharyngo-clavicularis externus, pharynx, and the occipito-clavicularis muscle, which is usually the source of the last dorsal branchial muscle vein, crossed the jugular and posterior encephalic veins and terminated in the thymus vein.

3. *Inferior Jugular Veins.*

These vessels return the venous blood from the ventral musculature of the head, heart, and ventral portion of the branchial arches and correspond in the main to the pharynx artery. The inferior jugular vein, however, does not become a paired vessel until near its termination in the precaval vein.

The inferior jugular vein may be said to arise from a small vein coming from the ventral surface of the tongue, the *lingual vein* (Pl. II, fig. 12; Lin. V.). This vein continuing caudad as the inferior jugular vein, passes in a median line above and between the hyohyoideus superior muscles, after which it receives 3 pairs of veins, the first pair coming from the outer posterior surface of the geniohyoideus muscles, the second from the inner surface of the hyohyoideus superior muscles (Pl. II, fig. 12; Hys.V.), and the third pair are the *ventral nutrient branchial veins* from the first branchial arch. The latter vessels (Pl. II, fig. 12; N.Br.V.) drain the ventral half of the first pair of arches. Each of them arises as a paired vessel in front of the first efferent branchial artery. The *nutrient filament veins* (Pl. I, fig. 2; N.Fil.V.) from one side empty into one of these branches and those from the opposite side into the other branch.¹ Further caudad these two branches unite forming a single nutrient branchial vein into which a few of the most ventral nutrient filament veins from both sides are poured. In front of this nutrient branchial vein, running along the cephalic margin of the arch, is another vein, which sends caudad cross-vessels that empty into the main ventral nutrient branchial vein. Continuing ventrad, cephalad of the efferent branchial trunk, the first ventral nutrient branchial vein empties into the inferior jugular vein. After collecting these veins the inferior jugular passes caudad, above the thyroid gland and the ventral aorta; receiving branches from the gland, other ventral nutrient branchial veins, and several small veins coming from the obliqui ventrales muscles. Emerging from the last pair of afferent branchial arteries the inferior jugular continues caudad, passing

¹ It is of interest to note that the nutrient filament veins come from the inner margins of their filaments; while the nutrient filament arteries are distributed to the outer margins.

between the ventral aorta and the transversus ventralis muscle, and when the posterior edge of this muscle is reached, which is about midway between the last pair of afferent branchial arteries and the ventricle, the inferior jugular bifurcates into a very large *right* and a much smaller *left inferior jugular vein* (Pl. II, fig. 12; R and L.I.J.V.). The course of each of these veins is then obliquely caudad, running along the ventral side of the pharynx close to the pharyngo-clavicularis internus muscle. They terminate by emptying into their respective precaval veins. Throughout their course they receive branches from the pharynx, the pharyngo-clavicularis internus and externus muscles, and shortly before dividing, the inferior jugular received branches from the pharyngo-hyoideus and transversus ventralis muscles, and the coronary vein.

The *coronary vein* (Pl. II, fig. 12; Cor.V.) arises from a dorsal and a ventral branch, which run parallel with their respective arteries. The dorsal vessel collects the venous blood from the anterior part of the ventricle and the bulbus arteriosus; while the ventral branch drains only the bulbus. About midway between the ventricle and the first pair of afferent branchial arteries these 2 branches unite on the left side of the ventral aorta in forming the main coronary vein, which finally empties into the inferior jugular shortly after it emerges from the last pair of afferent branchial arteries.

Beside this coronary vein, which drains the ventral aorta, bulbus, and anterior part of the ventricle there is another system of coronary veins, which terminate by emptying directly into the auricle. The outer layer of the ventricle is a mass of capillaries, which become collected on the ventral side into 4 or 5 veins that pass around to the dorsal side where some of them anastomose, forming 2 or 3 vessels, which penetrate the auricle close to the auriculo-ventricular valve. In one specimen several small veins were noticed to arise on, and penetrate the dorsal surface of the auricle.

In *Sebastodes melanops*, beside the large right and the smaller left inferior jugular veins, 2 other veins, laterad to these, were observed. They arose from the pharyngo-clavicularis internus and externus muscles, and passed caudad to empty into their respective precaval veins.

4. *Ventral Veins.*

These veins correspond to, and drain the region supplied by the posterior part of the ventral artery: namely, the ventral or pelvic fins, their muscles, and the ventral portion of the myotomes forming the thoracic walls. Considerable variation is shown in these veins, since they may arise as 2 rather large veins of equal size or one small vein and one large one, but the most common arrangement for *Ophiodon* is that shown in fig. 12.

The vessel designated as the *right ventral vein* (Pl. II, fig. 12; R.Ven.V.) is a deeper vessel than the ventral artery, and terminates in the left hepatic sinus. This vein may be said to have its source from 2 branches, a *right* and a *left ventral fin vein* (Pl. II, fig. 12; R. and L.Ven.F.V.), which have their origin in the right or left ventral fin ray canal. In these canals the veins run behind the arteries, and receive a branch from the center of each ray. Leaving the canal of the last rays each of these veins crosses above the corresponding ventral ray artery, and passes cephalad, for some little distance, between the ventral or pelvic superficial adductor muscle and the ventral myotomes. Then after uniting with its fellow, the combined trunk continues cephalad as the right ventral vein or the main ventral vein. Along its course this vein and its 2 branches receive numerous vessels. Soon after leaving the ventral fin canal, the left ventral fin vein receives a posterior ventral vein, which runs parallel with the corresponding artery. This branch receives several *ventral intercostal veins* (Pl. II, fig. 12; V.-Intc.V.) from either side. In addition to receiving a ventral intercostal vein from the septum between each alternate pair of myotomes, each ventral fin vein receives several branches from the superficial and profundus adductor muscles, and at least 2 branches, coming up between the pelvic bones from the superficial and profundus abductor muscles. The right ventral vein itself also receives at least 2 ventral intercostal veins from the right side. In the specimen from which fig. 12 was drawn the *left ventral vein* (L.Ven.V.) was a very short vessel, arising from several ventral intercostal veins from the left side, but in other specimens the left ventral vein was as large as the right, and the vessel designated as the *left ventral fin vein* (fig. 12;

L.Ven.F.V.) instead of uniting with the right ventral fin vein to form the right ventral vein, forms the principal venous supply for the left ventral vein.

In *Hexagrammos* and *Scorpaenichtys* the ventral veins are essentially the same as the last case described under *Ophiodon*; namely, the 2 ventral veins are of equal size, receiving their venous supply from the right and left sides respectively. In *Scorpaenichthys*, however, the right and left ventral fin veins do not leave the ventral fin ray canal with the artery from the last ray, as is the case with *Ophiodon* and *Hexagrammos*, but may leave the canal between any 2 rays, usually, between different rays in the 2 different fins. In *Sebastodes* these 2 veins are of equal size, but another condition is introduced. The 2 ventral fin veins leave the ventral fin canal with their respective arteries, anastomose, and the common trunk thus formed passes cephalad parallel with the ventral artery, between the two pelvic bones, and usually empties into the left ventral vein.

5. Subclavian Veins.

In *Ophiodon* there are 3 subclavian veins, returning the venous blood from the region of the pectoral arch. Two of these, coming from the outer or abductor muscles, unite in forming the subclavian sinus which empties into the sinus venosus in front of the precava, while the third one coming from the rays and the inner or adductor muscles, pierces the anterior fork of the kidney. This vessel does not empty directly into the cardinal trunk, but first breaks up into smaller vessels, which reach the cardinal through the renal veins.

Internal Subclavian or Subclavian Veins₍₁₎ (Pl. II, fig. 14; Sub.V.₍₁₎).—The vessel thus designated, in the main, corresponds with the internal subclavian artery. It receives its supply in part from the pectoral rays, and in part from the adductor muscles, situated on the inner side of the pectoral arch. This vessel has its origin from a dorsal and a ventral pectoral fin vein, which unite in the pectoral ray canal, thus forming a continuous vessel, which runs along behind the corresponding pectoral fin artery. Within this canal it receives a small vein returning the venous blood from each ray. In no 2 specimens

did these 2 veins leave the pectoral fin canal in the same places; in fact, they were not the same in the 2 different fins of the same fish. In the fin from which fig. 14 was drawn the dorsal branch left between the seventh and eighth rays, counting dorso-ventrad, and the ventral branch left in the neighborhood of the fourteenth ray. Each of these branches proceeded dorsad, for some little distance, along the inner surface of the superficial pectoral adductor muscle, and each branch received numerous smaller branches from the superficial and profundus adductor muscles. Uniting on the level with the scapula foramen they form the internal subclavian trunk, which continues dorsad behind the subclavian artery. Shortly before the kidney is reached it curves caudad, and passing between the first few spinal nerves and the superficial adductor muscle, pierces the ventral surface of the corresponding fork of the kidney. Once within the kidney the internal subclavian rapidly decreases in caliber, by sending off branches that break up into capillaries, which finally reach the cardinal through the renal veins.

The vein designated as the *external subclavian* or *subclavian vein*₍₂₎ (Pl. II, fig. 14; Sub.V.₍₂₎) has its origin from the superficial and profundus pectoral abductor muscles, on the outer surface of the pectoral arch. Coming through the scapula foramen, cephalad of the external subclavian artery, it receives a branch from the profundus adductor muscle, and then runs for a short distance below and behind the precaval vein, where it receives the vein designated as the *subclavian vein*₍₃₎ (Pl. II, fig. 14; Sub.V.₍₃₎). This vein takes its source from 2 branches, one coming from the ventro-cephalic portion of the profundus abductor muscle, and the other from the similar part of the profundus adductor muscle. The former penetrates the coracoid foramen, and unites with the latter in forming the main subclavian vein₍₃₎, which passes dorsad along the inner surface of the profundus adductor muscle. Leaving this muscle, subclavian vein₍₃₎ unites with the external subclavian vein to form the *subclavian sinus* (Pl. II, fig. 12; Sub.S.), which empties into the sinus venosus directly behind the precaval vein, but before uniting with the external subclavian, it receives a vessel formed from a branch from the clavicle and the *sterno-hyoideus vein* (Pl. II, figs. 12 and 14; Ster.V.).

In *Hexagrammos* and *Sebastodes* the subclavians are essentially the same as in *Ophiodon*, except that no vessel corresponding to subclavian vein₍₃₎ was observed. In *Scorpaenichthys* there were at least 3 *internal subclavian veins* (Pl. IV, fig. 30; Sub.V.₍₁₎); all of which broke up in the anterior fork of the kidney. The *external subclavian vein* in *Scorpaenichthys* (Pl. IV, fig. 30; Sub.V.₍₂₎) instead of emptying into the sinus venosus, breaks up in the anterior fork of the kidney, cephalad of the internal subclavians.

6. *Hepatic Portal System.*

This system of veins returns most of the venous blood from the stomach, spleen, cæca and intestine. Some of the blood, however, from the posterior part of the stomach and intestine, reaches the right cardinal through the posterior mesenteric vein. This vein anastomoses with the portal system in at least two places. In *Ophiodon* there are 2 distinct portal veins, which terminate in the right and left lobes of the liver. The right portal returns the blood from the right side of the stomach, spleen, and a portion of the intestine; while the left portal drains the cæca, ventral portion of the stomach, and a portion of the intestine. In *Ophiodon* these 2 systems remain quite well separated; nevertheless, their branches anastomose in several places in the region of the posterior end of the stomach, but within the liver none of their branches unite. Each of the portals breaks up into capillaries in its respective lobe, which reunite in forming the right and left hepatic veins, and these vessels unite in a sinus before emptying into the sinus venosus.

(a) *Right Portal Vein* (Pl. I, figs. 1 and 2; R.Por.V.).—In *Ophiodon* the right portal trunk is in itself a very short vessel, having its source from 2 principal trunks, one of them being the right gastric vein, coming from the stomach, and the other branch a vein formed by the union of the splenic and intestinal vein₍₁₎. The *right gastric vein* (fig. 1, R.Gas.V.) has its origin in the posterior or cardiac portion of the stomach, where it anastomoses with branch Z of the posterior mesenteric vein (fig. 1, P.Mes.V.) and the posterior gastric vein, which is a branch of the left portal. The course of the right gastric vein is

cephalad, below the right gastric artery and the right gastric ramus of the vagus. Throughout its course it receives numerous branches from the muscular coats of the stomach. Leaving the anterior part of the stomach it crosses above the corresponding artery and nerve, and the cœliac artery, and when about midway between the stomach and the caudal tip of the right lobe of the liver, directly behind a gland-like body marked G. it unites with *intestinal vein*₍₁₎. This vein (Pl. I, figs. 1 and 6; Int.V.₍₁₎) usually arises in the region of the rectum by anastomosing with branch Y of the posterior mesenteric vein (see fig. 1). In its cephalic course in the adipose tissue surrounding the intestine, lying below the corresponding artery, it ordinarily sends off from one to 3 branches, which empty into the right cæca vein or its posterior gastric branch. In the specimen from which fig. 1 was drawn 3 such vessels were given off. The 2 posterior ones emptied into the right posterior gastric vein and the anterior one into the right cæca vein. Throughout its entire course *intestinal vein*₍₁₎ receives numerous branches from the intestine and when the spleen is reached, which is in the neighborhood of the anterior or duodenum portion of the intestine, it receives a large vein from that organ. The *splenic vein* (Pl. I, figs. 1 and 6; Spl.V.) arises in the center of the spleen from a fan-like system of vessels, which unite in a common stem, that leaves the anterior part of the spleen with the splenic artery and soon empties into *intestinal vein*₍₁₎. Immediately after receiving the splenic vein, *intestinal vein*₍₁₎, usually, sends off or receives a *connecting vein* (Pl. I, figs. 1 and 6; C'.V'), which unites with the anterior intestinal or duodenum vein, a branch of the left portal. In another specimen this vein was seen to arise from the splenic instead of the intestinal vein. *Intestinal vein*₍₁₎ terminates by uniting with the right gastric vein, in the neighborhood of the right lobe of the liver, to form the main right portal trunk. As has already been stated this vessel (Pl. I, figs. 1 and 11; R.Por.V.) is in itself a very short trunk, which penetrates the apex of the right lobe of the liver, and exhausts itself in that gland by breaking up into numerous *interlobular veins* (fig. 11, I.Lob.V.), which finally terminate in numerous venous capillaries.

Shortly before entering the liver, however, the right portal receives a vein from a gland-like body, marked G in fig. 1, and the anterior gall-bladder vein. The latter vessel (fig. 11, A. G.Bl.V.) arises from the anterior part of the bladder, and like the corresponding artery, anastomoses with the posterior gall-bladder vein.

In some cases, as was also noted with the corresponding artery, intestinal vein₍₁₎ does not always have its origin in the rectum and anastomose with the posterior mesenteric vein and the vessels emptying into the right cæca vein; but sometimes arises much further cephalad, and the part of the intestine usually drained by this vessel was poured into the posterior mesenteric vein and the veins emptying into the right cæca vein.

(b) *Left Portal Vein* (Pl. I, figs. 1, 6 and 11; L.Por.V.). — This is somewhat the larger of the two portals. In *Ophiodon* it has its source, principally, from the right and left pyloric cæca veins and intestinal vein₍₂₎. Of the 2 *pyloric cæca veins*, the *right* (Pl. I, figs. 1 and 6; R.Cæ.V.) is the larger. Beside receiving 3 or 4 large branches coming from the cæca it receives a *right*, and a *left posterior gastric vein* (Pl. I, figs. 1 and 6; R, and L.P.Gas.V.). The right vessel comes from the right and ventral side of the posterior or cardiac portion of the stomach, where its branches anastomose with those of the right gastric vein and branch Z of the posterior mesenteric vein. In the specimen from which figures 1 and 6 were drawn the right posterior gastric vein received 2 branches from intestinal vein₍₁₎ and the right pyloric cæca vein received a third one. In those specimens in which these vessels unite with both intestinal vein₍₁₎ and the right pyloric cæca vein or its posterior gastric branch it would be possible for the blood to flow in either direction, but it is probable that the least resistance is toward the pyloric cæca vein. Shortly before the right pyloric cæca vein unites with the left in front of the pylorus, it receives a small vein from the pylorus. Usually the *left pyloric cæca vein* (see Pl. I, figs. 1 and 6), is much the smaller. It receives about 2 branches from the cæca and one or 2 small ones from the pylorus. Both of the pyloric cæca veins run outside of their

corresponding arteries and unite in forming the left portal trunk directly in front of the point of bifurcation of the cœliac artery. Near its origin from the union of the two pyloric cæca veins the left portal, or occasionally it is the right pyloric cæca vein, receives *intestinal vein*₍₂₎. This vein (Pl. I, figs. 1, 6 and 11; Int.V.₍₂₎) usually has its source from the ventral side of the intestine close to the rectum. Its course is cephalad in the adipose tissue below the intestine. Before going very far, however, it crosses to the upper side of the intestine, changing places with intestinal vein₍₁₎. Then proceeding cephalad above the artery until the duodenum is reached, it crosses over the intestine, intestinal artery₍₁₎, intestinal vein₍₁₎, the anterior part of the duodenum, the cœliac artery, and empties into the left portal close to its origin from the two pyloric cæca veins. Continuing cephalad for a short distance between the stomach and liver and to the left of the cœliac artery, the left portal receives the *anterior intestinal* or *duodenum vein* (Pl. I, figs. 1 and 11; A.Int.V.), which returns the blood from the anterior loop. The course of this vessel is at first directly behind the corresponding artery; then after passing under intestinal artery₍₁₎ and intestinal vein₍₁₎ it ordinarily gives off or receives the *connecting vein* (figs. 1 and 6; C.'V.'), a small vein which usually anastomoses with intestinal vein₍₁₎, a branch of the right portal. Then after passing over the anterior arm of the duodenum from which it receives a branch, it crosses the cœliac artery, and after following along behind the hepatic artery for a short distance terminates in the left portal. The left portal enters the dorsal surface of the liver through 5 large *radicals* or *terminal branches* designated by the letters a to e (figs. 6 and 11). These vessels immediately penetrate the large left lobe of the liver and break up into the *interlobular veins* (fig. 11; I.Lob.V.), which, in turn, break up into venous capillaries. Usually several veins from the ventral surface of the stomach, designated as *ventral gastric veins* (fig. 6; V.Gas.V.), empty into some of these radicals, and some of the ventral gastric veins often penetrate the dorsal surface of the liver and break up into venous capillaries without emptying directly into the portal system. The *posterior gall-bladder vein* (fig. 11; P.G.Bl.V.), which arises on the

posterior dorsal surface of the bladder and anastomoses with the anterior gall-bladder vein, empties into radical a of the left portal. This radical may also receive a similar, but smaller vein from the ventral surface of the bladder.

An interesting vessel in *Ophiodon* is the *left gastric vein* (Pl. I, figs. 1 and 6; L.Gas.V.), since it is not connected with the portal system but terminates directly in the precava. This vein has its origin in 2 branches from the left side of the stomach, on either side of the left gastric artery. The ventral branch is usually the larger; arising from the extreme posterior end of the stomach, its branches anastomose with those of branch Z of the posterior mesenteric vein. When the anterior portion of the stomach is reached the smaller left gastric branch crosses over the left gastric artery and joins the main stem of the left gastric, and the combined vessel passes forward above the left gastric ramus of the vagus and empties into the precava. Still another small gastric vein arises from the anterior dorsal surface of the stomach and terminates in the precava, above the main left gastric vein.

As in other vertebrates the intestinal, gastric, and cæca veins arise from capillaries in the connective tissue layer of the crypts and the larger branches run in the muscular layers. Within the liver the terminal branches or radicals of the two portals exhaust themselves in the *interlobular veins* (fig. 11, I.Lob.V.), which break up into venous capillaries, that reunite in forming the *central* or *intralobular veins*, from which the *sublobular veins* (fig. 11, S.Lob.V.) have their origin. The latter vessels are the radicals, which by uniting, form the 2 *hepatic veins* (fig. 11, R. and L.Hep.V.); which come from the right and left lobes respectively, and terminate in a *hepatic sinus* that enters the sinus venosus from the rear. In the liver the main trunks of the hepatic system lie beneath those of the portal system.

As in the arteries, most of the variation of the veins in this group occurs in the viscera. Nevertheless, all of the species examined had a distinct right and left portal, which break up in the right and left lobes respectively. In *Sebastodes* both portals terminate in a common portal. In *Hexagrammos* the

right portal anastomoses with radical *a* of the left portal. In *Scorpaenichthys* this union sometimes occurs, but with *Ophiodon* it has never been observed. However, both *Ophiodon* and *Scorpaenichthys* have a connecting vein that interlinks these 2 systems in the region of the spleen.

(c) *Right Portal in Hexagrammos, Scorpaenichthys and Sebastodes*. — In *Hexagrammos*, as with *Ophiodon*, this vessel (Pl. IV, fig. 27; R.Por.V.) has its origin from an intestinal, and a gastric vein. The *right gastric vein* (Pl. IV, fig. 27; R.-Gas.V.) is essentially the same as in *Ophiodon*, except that there is no posterior mesenteric vein for it to anastomose with on the apex of the stomach, and it runs on the opposite side of the artery from what it does in the other 3 genera. The vessel designated as *intestinal vein*₍₁₎ (Pl. IV, fig. 27; Int.V.₍₁₎) is the principal intestinal vein. It arises in the region of the rectum, but soon crosses over to follow along the posterior arm of the ileum from which it receives several branches before receiving the *splenic vein*¹ (fig. 27; Spl.V.), and another good-sized branch which drains the region supplied by intestinal artery₍₂₎. Passing cephalad, parallel with, but below the corresponding artery it crosses over intestinal vein₍₂₎, the anterior part of the intestine, the coeliac artery, radical *a* of the left portal, and when the stomach is reached unites with the right gastric vein to form the *right portal* (fig. 27, R.Por.V.). This vessel immediately passes under intestinal artery₍₁₎, between the coeliac and right hepatic arteries, along the posterior surface of the gall-bladder, but behind the right hepatic artery. Here it receives a few small branches from the bladder and terminates in 2 or 3 small branches in the right lobe of the liver, and also anastomoses with radical *a* of the left portal.

In *Scorpaenichthys* the *right portal* (Pl. IV, fig. 29; R.Por.V.) has its source entirely from the right gastric and the splenic veins. All of the intestinal veins empty into the left portal. The *right gastric vein* (fig. 29, R.Gas.V.) is practically the same as in *Ophiodon*; arising in the cardiac end of the stomach,

¹ In *Hexagrammos* the spleen is located much further caudad than is the case with any of the other genera studied. Its position is much nearer the vent than the stomach.

it anastomoses with branch Z of the posterior mesenteric, and the posterior gastric veins. The *splenic vein* (fig. 29, Spl. V.) leaves the anterior surface of the spleen, which is located directly above the pylorus, and passes forward to unite with the right gastric vein in forming the right portal, but immediately after leaving the spleen it receives the *posterior gastric vein* (fig. 29, P.Gas.V.), which in *Ophiodon* emptied into the right cæca vein, a branch of the left portal. The right portal, itself, is almost identical with the same vessel in *Ophiodon*; it receives a small vein from a gland-like body marked G, and shortly before entering the right lobe of the liver receives the anterior gall-bladder vein which does not anastomose with the posterior gall-bladder vein as in *Ophiodon*. Usually the right portal breaks up in the small right lobe of the liver without anastomosing with terminal branch *a* of the left portal.

Beside the ordinary branches which go to make up the right portal in *Ophiodon*, there is an additional one in *Sebastodes*, namely, the *anterior air-bladder* or *air-bladder retia mirabilia vein* (Pl. IV, fig. 31; A.Bl.V.). This vessel arises from the retia mirabilia venous capillaries, which are continuous with, and run parallel to, the corresponding arterial retia mirabilia capillaries. These venous capillaries unite in forming larger vessels that terminate in the main anterior air-bladder vein, which pierces the ventral wall of the bladder and empties into the *right gastric vein*. The latter vessel, as in *Hexagrammos*, has its origin in the posterior end of the stomach without having any posterior mesenteric vein with which to anastomose. Shortly after receiving the anterior air-bladder vein the right gastric receives the vessel designated as intestinal vein₍₁₎. This vessel (fig. 31, Int.V.₍₁₎) arises in the rectum and drains the posterior portion of the intestine. In its cephalic course, parallel with the corresponding artery, it follows along the posterior border of the spleen; in *Sebastodes flavidus* (fig. 33) it was seen to unite with the splenic vein as in *Ophiodon*, while in *Sebastodes auriculatus* both vessels emptied separately into the right gastric vein. Shortly before joining the right gastric, or splenic vein as it is in *S. flavidus*, intestinal vein₍₁₎ usually receives a posterior gall-bladder vein (figs. 31 and 33, P.G.Bl.V.)

and an anterior intestinal vein. Soon after leaving the spleen, in front of the corresponding artery, the *splenic vein* (fig. 31, Spl.V.) receives the *posterior gastric vein* (fig. 31, P.Gas.V.) from the rear. This vessel arises from the ventral surface of the stomach immediately behind the pylorus, and receives a small branch coming from the ventral surface of the posterior end of the intestine. After receiving this branch the posterior gastric vein passes between the spleen and the cæca and joins the splenic vein. The splenic vein in *Sebastodes auriculatus* after crossing intestinal vein₍₂₎, and intestinal artery₍₂₎ unites with the right gastric component, directly below intestinal vein₍₁₎, to form the main right portal. Shortly before entering the liver the right portal receives a small branch coming from a gland-like body marked G (figs. 33 and 34), anastomoses with the common portal trunk (which will be fully described under the head of the left portal), and in its course in the right lobe of the liver receives the *anterior gall-bladder vein*. This vessel (figs. 33 and 34, A.G.Bl.V.) is always present, and sometimes returns the entire blood from the gall-bladder. Its course is to the right and above the ductus choledochus.

(d) *Left portal vein in Hexagrammos, Scorpaenichthys, and Sebastodes.* — In *Hexagrammos* the two pyloric cæca veins are essentially the same as in *Ophiodon*, except that neither of them receives a posterior gastric vein from the cardiac end of the stomach. Close to its origin from the two pyloric cæca veins the *left portal* (Pl. IV, figs. 27 and 28; L.Por.V.) receives a branch from the anterior arm of the ileum, designated as intestinal vein₍₂₎ (fig. 27, Int.V.₍₂₎), but which perhaps corresponds to an elongated anterior intestinal or duodenum vein. On the dorsal surface of the liver the left portal breaks up into 3 radicals (figs. 27 and 28, *a*, *b* and *c*). Radical *a* is prolonged to anastomose with the right portal, and soon after leaving the main stem receives a very large *ventral gastric vein* (fig. 28, V.Gas.V.), which may to some extent take the place of the absent left gastric vein.

In *Scorpaenichthys* the *left portal* (Pl. IV, figs. 29 and 30; L.Por.V.) receives both of the intestinal veins. The pyloric cæca veins are essentially the same as in *Ophiodon*, except that

the pyloric branch of the left one extends backward on the cardiac portion of the stomach as a sort of posterior gastric vein, and anastomoses with branches of the posterior mesenteric vein; while the posterior gastric vein proper empties into the splenic vein instead of the right cæca vein as in *Ophiodon*. *Intestinal vein*₍₁₎ (fig. 29, Int.V.₍₁₎) arises from the posterior end of the iliac loop; the most dorsal of its branches anastomoses with branch Z of the posterior mesenteric vein, and it receives a branch coming from the region of the rectum. In its cephalic course, intestinal vein₍₁₎ passes between the two arms of the ileum, and receives a branch from the posterior part of the intestine designated as *intestinal vein*₍₂₎ (fig. 29, Int.V.₍₂₎), and the *anterior intestinal* or *duodenum vein* (fig. 29, A.Int.V.). The combined intestinal trunk thus formed passes under the anterior arm of the duodenum and joins the left portal close to its origin from the 2 pyloric cæca veins, but before emptying into the left portal it receives or sends off a *connecting vein* (fig. 29, C'.V'.) that unites with the splenic vein. After reaching the great left lobe of the liver the left portal immediately gives off to each side numerous terminal branches or radicals; which break up into the interlobular veins. As in *Ophiodon*, except in a very few cases, radical *a* of left portal does not anastomose with the right portal; it, however, receives the *posterior gall-bladder vein* (fig. 30, P.G.Bl.V.), and also a very large *ventral gastric vein* (fig. 30, V.Gas.V.), which anastomoses anteriorly with the left gastric vein and posteriorly with a branch of the posterior mesenteric vein.

As in *Ophiodon* there is a *left gastric vein* (fig. 30, L.Gas.-V.) emptying directly into the precava and two smaller left gastric veins; one of which empties into the precava and the other into the left fork of the kidney; while the main left gastric vein anastomoses with branches of the ventral gastric vein, which has branches that anastomose with branches of the posterior mesenteric vein.

The *left portal* in *Sebastodes* (Pl. IV, figs. 30 and 31; L.-Por.V.) is a rather insignificant vessel, having its source from a vessel designated as intestinal vein₍₂₎ and the right pyloric cæca vein. Intestinal vein₍₂₎ (fig. 31, Int.V.₍₂₎) returns the

blood from the ileum; passing beneath intestinal vessels₍₁₎ and the splenic vessels, it crosses under the anterior part of the spleen, where it joins a common trunk formed by the union of the right pyloric cæca vein and a very large *pylorus vein* (fig. 32, Pyl.V.). The common trunk thus formed is the left portal, but instead of breaking up into numerous radicals it empties with the *left pyloric cæca vein* (fig. 32, L.Cae.V.) and the *ventral gastric vein* (fig. 32, V.Gas.V.) into the *common portal vein* (fig. 32, C.P.V.). By anastomosing with the common portal, the right portal might also be said to empty into the common portal.

Summary of the Portals.—As in the case with the corresponding arteries, intestinal veins_(1 and 2) are arbitrary names given to the two principal intestinal veins. Considerable variation occurs in these two veins in the same species, but in *Ophiodon* the vessel designated as intestinal vein₍₂₎ arises in the posterior part of the intestine, and in its cephalic course along the ventral side of the intestine receives the splenic vein, and joining the right gastric vein forms the right portal. The corresponding vein in *Hexagrammos* pursues a similar course; while in *Scorpanichthys* the two intestinal veins unite and empty into the left portal; and in *Sebastodes* intestinal vein₍₁₎ drains only the posterior part of the intestine, and may unite with the splenic vein, or each of these vessels may empty separately into the right gastric vein to form the right portal. In every case the right portal breaks up in the right lobe of the liver. The vessel designated as intestinal vein₍₂₎ in *Ophiodon* arises from the ventral posterior end of the intestine and terminates in the left portal. In *Hexagrammos* this vessel might possibly correspond to an elongated duodenum artery; while in *Scorpanichthys* if this vessel is represented at all, it unites with intestinal vein₍₁₎ and the combined trunk empties into the left portal; and in *Sebastodes* this is the principal intestinal trunk, arising from the iliac loop it unites with the right pyloric cæca vein to form the left portal trunk. All the genera but *Hexagrammos* have a posterior gastric vein; in *Ophiodon* it terminates in the right pyloric cæca vein; while in *Scorpanichthys* and *Sebastodes* it empties into the splenic vein, a branch of the right portal.

Ophiodon and *Scorpaenichthys* have a left gastric vein, which empties into the precava; while in *Sebastodes* and *Hexagrammos* the ventral gastric veins are greatly enlarged, and evidently to some extent take the place of this vessel, nevertheless in *Scorpaenichthys* the ventral gastric is a good sized vessel and anastomoses with the right gastric vein. In *Ophiodon* and *Scorpaenichthys* there is a grand anastomosis in the cardiac portion of the stomach of the branches of the right gastric, left gastric, ventral gastric, posterior gastric and posterior mesenteric veins. Usually the right and left pyloric cæca veins unite to form the left portal, but in *Sebastodes* the right pyloric cæca vein joins intestinal vein₍₂₎ to form the left portal, and the left pyloric cæca vein empties into the common portal trunk. *Ophiodon* and *Scorpaenichthys* have a connecting vein in the region of the spleen that links the 2 portal systems; in *Ophiodon* it usually connects intestinal vein₍₁₎ with the anterior intestinal or duodenum vein; while in *Scorpaenichthys* it connects the splenic and common intestinal veins. Within the liver the 2 portals are usually distinctly separated in *Ophiodon* and in *Scorpaenichthys*; while in *Hexagrammos* radical *a* of the left portal anastomoses with the right portal; and in *Sebastodes* both portals together with the ventral gastric and left pyloric cæca veins unite in forming a common portal trunk, which gives off numerous radicals that break up into the interlobular veins.

7. Renal Portal System.

Like the hepatic portal system the renal portal system consists of two principal venous trunks, which are connected by a system of venous capillaries within the kidney. One of these trunks, the caudal vein, arises in the region of the tail and pursues a cephalic course in the hæmal canal, immediately below the caudal artery, receiving the neural veins from above and the hæmal veins from below. Piercing the dorsal surface of the kidney it bifurcates into a right and left renal portal vein; each of these sends off numerous afferent renal veins that after breaking up into capillaries reunite in numerous efferent renal veins, which terminate in, and form, the right cardinal vein. This trunk starts in the posterior end of the kidney, passing

cephalad through the center of this organ; it follows the right fork of the kidney and unites with the right jugular to form the right precava. Throughout its course it receives numerous branches, which will be described in detail later on. There is also a smaller left cardinal for the left lobe of the kidney, which will also be considered under a separate head.

(a) *Caudal Vein* (Pl. I, figs. 1, 7, 8, 9 and 10; Cau.V.).—This trunk has its origin in the region of the last vertebra from a right and left branch; both of which have a more superficial course than the corresponding arteries. The *right caudal vein* (fig. 7, R.Cau.V.) is much the shorter; it arises from the region of the tail and passes cephalad between the superficial and profundus muscles, and when the last vertebra is reached, curves inward, and after receiving a dorsal branch joins the larger *left caudal vein*. The latter vessel (figs. 1 and 7; L.Cau.V.) has its origin from a dorsal and a ventral branch in the caudal fin ray canal. These branches lie immediately behind the corresponding lymphatic and arterial vessels. They receive a branch from the central canal of each ray, coming from the fin membrane and the fin ray muscles. Uniting between the two hypural bones the dorsal and ventral branches form the *left caudal vein* (figs. 1 and 7, L.Cau.V.), which passes cephalad between the superficial and profundus caudal fin muscles, receiving branches from each. In the region of the last vertebra it receives a dorsal branch and curves inward to unite with the right caudal vein, but before joining the left caudal vein to form the main caudal vein, each of the caudal veins appears to receive a vessel from the caudal lymphatic sinus. The course of the caudal vein is cephalad in the hæmal canal, immediately below the caudal artery; and in its course to the kidney receives a dorsal branch from in front of each alternate neural spine, and a ventral branch from in front of each alternate hæmal spine.

Each *neural vein* (fig. 1; Neu.V.) has its origin from a cephalic and a caudal branch; the latter returns the venous blood from superficial and profundus levator and depressor muscles of that ray; while the former returns the blood from the corresponding muscles of the preceding ray, and each

branch receives a vessel coming from behind the ray. These 2 branches unite at about the level of the apex of the neural spine, forming the neural vein proper. At this point the neural vein receives the *dorsal lateral vein* (fig. 1; D.Lat.V.), returning the blood from the dorsal region of the 2 neighboring myotomes, and immediately after receiving this branch the neural vein passes obliquely ventrad between the neural lymphatic vessel and the neural spine. Then curving forward and outward it crosses the neural canal, the centrum, the dorsal aorta, and empties into the caudal vein. In crossing the vertebral column it receives a *spinal vein*, coming through the spinal foramen from the myel, and the *median lateral vein* (fig. 1; M.Lat.V.), returning the blood from the central region of the 2 adjacent myotomes. The *hæmal veins* pursue a similar course from the ventral side of the body. Each of these vessels (fig. 1; Hæ.V.) has its source from the superficial and profundus levator and depressor muscles of 2 successive anal rays. In the region of the apex of the hæmal spine it receives the *ventral lateral vein* (fig. 1; V.Lat.V.), coming from the ventral portion of the two adjacent myotomes. Then passing obliquely dorsad between the hæmal lymphatic vessel and the hæmal spine it empties into the caudal vein. This is the normal arrangement of a neural or a hæmal vein; occasionally, however, a neural or a hæmal vein may drain the region of 3 or even 4 myotomes, and a neural vein may cross either side of the vertebral column. Usually between the first and second caudal vertebræ the caudal vein receives the *urinary bladder vein* (figs. 1 and 10; Ur.B.V.), coming from the posterior surface of the bladder. Very often, however, as is shown in fig. 10, this vein does not empty into the caudal vein, but penetrates the posterior ventral end of the kidney and reaches the cardinal through the renal veins.

After passing through the hæmal canal of the first caudal vertebra the caudal vein curves ventrad and pierces the dorsal surface of the kidney and becomes the renal portal vein.

Shortly after the caudal vein, or renal portal as it really is, penetrates the kidney it receives a rather large trunk designated as the *posterior mesenteric vein* (Pl. I, figs. 1 and 10; P.-

Mes.V.). This vessel arises from 2 good sized branches designated as Y and Z (see fig. 1). Branch Z which is strictly a gastric vein, takes its origin from several branches coming from the posterior or cardiac end of the stomach; one of which anastomoses with the right gastric vein; and 2 other branches anastomose with branches of the left gastric and posterior gastric veins. The course of branch Z is dorso-caudad; passing to the left of the intestine and its vessels, it unites with branch Y directly below the reproductive organs. Branch Y, which is distinctly an intestinal vein, drains the posterior end of the intestine, and usually anastomoses with intestinal vein₍₁₎; passing caudad it joins branch Z in forming the main posterior gastric stem, which passes between the reproductive organs, without receiving any branches, penetrates the posterior ventral surface of the kidney, and passing to the left of the right cardinal empties into the renal portal vein. It would be possible for the blood in the posterior mesenteric to flow in either direction, but it is probable that the least resistance is toward the kidney.

After receiving the posterior mesenteric vein the caudal or renal portal vein bifurcates into a *right* and a *left renal portal vein* or *vena renalis advehens* (figs. 1 and 10; Ren.P.V.). These trunks run cephalad for some little distance through the dorso-lateral part of the kidney, and gradually decrease in caliber by giving off numerous ventral branches, the *afferent renal veins* or *venae renales advehentes* (figs. 1 and 10, A.Ren.V.). These vessels break up into rather coarse venous capillaries near the lateral surface of the kidney, and become collected ventrad and mesad by the small *efferent renal veins* or *venae renales revehentes* (figs. 1 and 10; E.Ren.V.). A cross section through an injected kidney hardened in formalin shows us that these vessels, many of which are visible from the ventral side of the kidney, empty into the right cardinal from every direction.

(b) The *right cardinal vein* (Pl. I, figs. 1, 5 and 10; R.Car.V.), which is the principal cardinal has its source mainly from the efferent renal veins; it arises in the extreme caudal end of the kidney, below the caudal vein, and passes

cephalad through the center of the kidney until the kidney forks, when it follows the right fork. In the region of the last branchial arch it unites with the right jugular in forming the *right precava* (Pls. I and II, figs. 5 and 12; Prec.V.) or the *ductus Cuvierii* as it is often called, which encircles the right side of the œsophagus and empties into the sinus venosus in front of the subclavian sinus.

(c) *Other Vessels Emptying into the Kidney.* — Beside the posterior mesenteric and caudal veins there are several other vessels, which penetrate the kidney and reach the right cardinal in one way or another.

First under this head might be mentioned the *spermatic veins*. In the female (fig. 1) numerous branches arise from the lateral surfaces of the ovaries and unite in a longitudinal vessel, that has its origin from the anterior surface of the urinary bladder and the oviduct. From this longitudinal vessel at least two spermatic veins (fig. 1; Sper.V.) have their origin; passing dorsad they terminate in one way or another in the kidney: they may empty directly into the right cardinal, or the renal portal vein, or they may reach the right cardinal through the efferent renal veins. In the male (see fig. 10) there is no longitudinal trunk, and the spermatic veins arise directly from numerous branches coming from the inner surface of the testes. In this specimen the most anterior spermatic vein emptied into an afferent renal vein, the second one broke up into capillaries, and the last 2 joined the posterior mesenteric vein within the kidney. The *neurals* as in the caudal region drain the region of 2 myotomes, passing ventrad between the neural lymphatic vessel and the neural spine, they penetrate the dorsal wall of the kidney, but instead of emptying directly into the right cardinal, break up into capillaries that reunite in the efferent renal veins. The *intercostal veins* (fig. 1; Intc.V.) corresponding to the hæmal veins of the caudal region, arise from 2 myotomes of the thoracic walls; passing dorsad behind the intercostal lymphatic vessel they penetrate the ventro-lateral edge of the kidney, break up into capillaries, and reach the right cardinal through the efferent renal veins. In the cephalic part of the thoracic wall they anastomose ventrally with the ventral intercostal

veins. Usually, there are 2 *suprarenal veins* (fig. 10, Sr.V.), which pass inward and join the right cardinal.

(d) The *left cardinal vein* (figs. 1 and 5; L.Car.V.) is a very short and unimportant vessel; having its source entirely from the anterior end of the left fork of the kidney. The blood from the posterior part of this fork reaches the heart through the right cardinal. The left cardinal unites with the left jugular in forming the left precava, which passes around the left side of the œsophagus and terminates in the sinus venosus.

(e) *Renal Portal System in Scorpænichthys, Hexagrammos and Sebastodes*. — In each of these genera the renal portal system is in the main substantially the same. Some minor variations are noted in the 3 following paragraphs.

The renal portal system in *Scorpænichthys* is essentially the same as in *Ophiodon*. The caudal vein after passing through the hæmal canal of the first caudal vertebra penetrates the dorsal surface of the kidney, and breaks up into two renal portal veins. As in *Ophiodon* a *posterior mesenteric vein* (fig. 29, P.Mes.V.) is also present, which arises from a gastric and an intestinal branch, and after passing over the urinary bladder from which it receives a branch, penetrates the posterior apex of the kidney, terminating in the renal portal; but the distance it has to go cephalad in the kidney is much greater than in *Ophiodon*, and numerous branches are given off, which reach the cardinal through the efferent renal veins; so that the posterior mesenteric vein is much reduced in caliber upon joining the renal portal. It is of interest to note in this connection that in *Enophrys* and *Calycilepidotus*, 2 genera of the family Cottidæ, no such vessel as the posterior mesenteric was noticed. As regards the spermatic veins, they are also of especial interest, coming in midway between *Ophiodon* and the peculiar arrangement found in *Sebastodes*. In the female there is a *right* and a *left spermatic vein* (fig. 29, R. and L.Sper.V), each of which receives numerous branches coming from the lateral surfaces of their respective ovaries. From each of these longitudinal veins there arise a cephalic and a caudal vessel; both of which unite with corresponding vessels from the opposite side to form the *spermatic veins* proper (fig. 29; Sper.V._{1 and 2}), and

each of these veins empties directly into the right cardinal, which in *Scorpaenichthys* runs along the ventral surface of the kidney. In both male and female the right and left spermatic veins are continued some little distance cephalad of the reproductive organs, and empty into their respective cardinal veins, a little behind the point of union of the cardinals with the jugulars to form the precava.

The *caudal vein* (fig. 27; Cau.V.) in *Hexagrammos* after passing through the first caudal vertebra gives off an *anterior* and a *posterior renal portal vein* (fig. 27; Ren.P.V.) The former is the principal renal portal vein; it continues cephalad along the dorsal surface of the kidney, and breaks up into numerous afferent renal veins. In one specimen this vein appeared to empty directly into the right cardinal vein. The smaller posterior renal portal breaks up in the caudal end of the kidney. One of its branches receives the vein designated as the *urinary bladder vein* (fig. 27; U.Bl.V), which may to some extent be analogous to the posterior mesenteric vein of *Ophiodon* and *Scorpaenichthys*; it has its source from a meshwork of small veins on the rectum, which anastomose with branches of intestinal vein⁽¹⁾; passing across and along the dorsal surface of the bladder from which it receives several branches, it pierces the ventro-caudal end of the kidney, and gives off several branches in the kidney before uniting with a branch of the renal portal. The *right cardinal* (fig. 27; R.Car.V.) as in the other genera arises in the extreme posterior end of the kidney, and passing cephalad close to the ventral wall, unites with the right jugular in the right fork of the kidney to form the right precava. The veins from the caudal region of the ovaries empty into a longitudinal vessel that passes between the ovaries; farther forward this vein bifurcates, one branch running along the dorsal surface of the left ovary and the other along the right; both of them receiving numerous branches from the lateral surfaces of their respective ovaries. From the right longitudinal spermatic vein there arise an anterior and a posterior branch, both of which unite with the corresponding branches from the left longitudinal spermatic vein in forming the main *anterior* and *posterior spermatic veins* (fig. 27, Sper.V.⁽¹⁾ and ⁽²⁾) which empty directly into the right cardinal.

All species of *Sebastodes* examined had a distinct renal portal system, which in the main resembled *Ophiodon*; however, the renal portal veins extend much further cephalad, there is always one or more posterior air-bladder veins emptying into the renal portal system, and there is no posterior mesenteric vein. The kidney itself differs considerably in shape from that of the other genera; while it usually occupies a large portion of the dorsal part of the short thoracic cavity, still a large portion of the organ is crowded cephalad into the two forks. The *caudal vein* (Pl. IV, fig. 31; Cau.V.) after piercing the posterior dorsal side of the kidney continues cephalad along the dorsal surface of the kidney for some little distance as a *renal portal vein* and not until the kidney forks does this vein separate into the *renal portal veins* (fig. 31, Ren.P.V.). These veins continue cephalad in their respective lobes until near the point of union of the cardinals with the jugulars, giving off numerous afferent renal veins, and the renal portal itself receives the following vessels. First, the *spermatic vein* (fig. 31; Sper.V.), which is formed from the posterior union of the right and left spermatic veins. In its dorsal course about midway between the reproductive organs and the kidney it receives the *urinary bladder vein* (fig. 31; Ur.Bl.V.), and immediately before emptying into the renal portal, a small *suprarenal vein*. Shortly after receiving the spermatic, the caudal or renal portal receives a rather large *posterior air-bladder vein* (fig. 31; P.A.Bl.V.), which arises from a regular network of vessels on the posterior end of the air-bladder. In the specimen from which fig. 31 was drawn, two smaller posterior air-bladder veins were also noticed; one of which terminated in the renal portal vein, and the other in the right cardinal. Usually, however, there is but one posterior air-bladder vein, and it may empty into either the right cardinal or the renal portal vein. The right cardinal is almost identical to the similar vessel of the other genera, and a description of it is unnecessary.

VIII. VASCULAR SYSTEM IN ANOPLOPOMA.

Three specimens of this species were brought in by Chinese fishermen when this paper was about finished. All were in-

jected, but only one satisfactorily, the other specimens having been badly torn by the hooks. Upon dissection several interesting variations were noticed, and it seemed desirable to include a representative of the family *Anoplopomatidae* in this paper.

Carotid Arteries.—In *Anoplopoma* there are no common carotids; both carotids arise separately from the dorso-cephalic corner of the first efferent branchial artery. The *internal carotid* (fig. 35; I.Car.A.), which is given off first, presents no peculiarities. While the *external carotid* (fig. 35; E.Car.A.) is a much smaller vessel than in the other genera, and simply supplies the facial region without anastomosing with the hyoidean artery to form the mandibular artery; it immediately gives off the vessel designated as the *pseudobranchial* or *afferent pseudobranchial artery* (fig. 35; Ps.A.), which is as large as the external carotid, and which might be said to arise with the external carotid from the first efferent branchial artery. The course of the pseudobranchial artery is ventrad behind the hyomandibular, exhausting itself by giving off numerous afferent pseudobranchial filament arteries. Near its distal end the pseudobranchial artery receives the dorsal branch of the hyoidean artery, and it is probable that the hyoidean artery furnishes the pseudobranch, especially the ventral part of it, with some of its blood supply, but most of it evidently comes from the pseudobranchial artery, which is much larger at its source from the external carotid than at the point of anastomosis with the hyoidean artery. This arrangement somewhat resembles the pseudobranchial supply in *Gadus*, according to Müller (50) and Parker (61), but differs from it considerably. In *Gadus* the afferent pseudobranchial artery is a branch of the hyoidean artery, and the dorsal continuation of the main stem, which is much reduced in caliber, anastomoses with the internal carotid of the circulus cephalicus.

Hyoidean Arteries (fig. 35; Hyo.A.).—One of the most striking differences in the circulatory system of *Anoplopoma* is in connection with this vessel. As in *Ophiodon* each hyoidean artery has its origin from the ventral ends of the first efferent branchial artery. Passing along the dorsal surface of the hyoid arch it gives off the characteristic branch to the branchiostegal

rays and then follows along in front of the interhyal, but when the preopercle is reached, instead of passing through a foramen formed by the symplectic, hyomandibular, and preopercular and anastomosing with the facialis-mandibularis artery to form the mandibular artery as in *Ophiodon*, it bifurcates; the ventral branch passes through the above mentioned foramen to become the *mandibular artery* (fig. 35, Man.A.); while the dorsal branch passes along the inner surface of the preopercle, gives off a rather large opercular artery, and terminates in the pseudobranchial artery.

Jugular Veins (fig. 35, J.V.).—The jugulars and their branches are practically the same as in *Ophiodon*.

The first pair of *epibranchial arteries* (figs. 35 and 36; Epbr. A.₍₁₎) unite in forming the dorsal aorta, and the second pair, the cœliaco-mesentric; there is an opening into the aorta from the cœliaco-mesenteric artery, corresponding to the common chamber of *Ophiodon*, but the subclavians arise separately from the dorsal aorta, opposite the opening into the cœliaco-mesenteric.

Subclavian arteries.—Each subclavian (fig. 36, Sub.A.) after leaving the head kidney passes to the inner musculature of the corresponding pectoral fin. Here it separates into the subclavian artery proper, which is essentially the same as in *Ophiodon*, and a *hypobranchial artery*. This vessel (fig. 36; Hypobr.A.) passes ventrad a short distance, gives off a large branch, designated as the *posterior ventral artery* (fig. 36; Ven.A.₍₁₎) which passes ventro-caudad, supplying the ventral fin musculature and terminates in the right and left ventral fin arteries. The main stem of the hypobranchial passes cephalad and ventrad, and together with the corresponding vessel from the opposite side anastomoses with the anterior ventral artery. On the left side the hypobranchial artery has no posterior ventral branch. The hypobranchial artery in *Anoplopoma* may not be homologous with the similar named vessel in *Ophiodon*, which is really a branch of the ventral artery and anastomoses with a branch of the subclavian.

Only one *subclavian venous trunk* (fig. 36; Sub.V.₍₂₎) was noticed. It arose from an external and an internal branch.

The outer subclavian vein penetrated the scapula with the corresponding artery and joined the internal subclavian vein in forming the common subclavian trunk, which terminates in its respective horn of the kidney.

The vessel designated as the *anterior ventral artery* (fig. 36; Ven.A.) arises from the ventral union of the second right and left efferent branchial arteries; principally, however, from the second left efferent branchial artery. After passing over the combined trunk of the third and fourth afferent branchial vessels it gives off the *pharynx artery*. This vessel (fig. 36; Phar.A.) supplies the pharynx region, and soon sends off the *coronary artery* (fig. 36; Cor.A), which passes along the dorsal side of the ventral aorta to the heart. In all other genera studied the pharynx artery arose directly from the second or the third efferent branchial arteries. The anterior ventral artery evidently corresponds to the ventral artery of the other species; except that it extends only to the origin of the pelvic arch. In addition to giving off the pharynx artery it sends off branches to the sterno-hyoideus muscle and anastomoses with the 2 hypobranchial arteries. It would be possible, however, in *Anoplopoma* for blood in the anterior ventral artery to reach the ventral fins by passing through the right hypobranchial artery into the posterior ventral artery. By the separation of the right hypobranchial from the subclavian we would have in the anterior ventral, right hypobranchial, and posterior ventral arteries an irregular shaped vessel corresponding somewhat to the ventral artery of the other genera.

As in *Sebastodes*, there is in addition to the main inferior jugular and left branch, a right inferior jugular, which drains the ventral branchial muscles from the right side and empties into the right precava.

Celiaco-mesenteric Artery.—This trunk (fig. 37; Cœ.Mes.-A.) upon reaching the œsophagus separates into the celiac and mesenteric arteries respectively. The *mesenteric artery* soon divides into intestinal artery₍₁₎ and a short stem from which the *right and left gastric arteries* have their source. The latter vessel (figs. 37 and 38; L.Gas.A.) makes a cephalic curve across the œsophagus and continues on the left side of the

stomach to the apex; while the former (fig. 37; R.Gas.A.) crosses the corresponding vein and continues parallel with it along the right and dorsal side of the stomach to the apex. From the right gastric the *posterior gall-bladder artery* is given off to supply the posterior two thirds of the bladder, and a small branch is also given off to a gland-like body marked G. Intestinal artery₍₁₎ (fig. 37; Int.A.₍₁₎) crosses over the right portal and continues caudad to the right of intestinal vein₍₁₎. Directly in front of the spleen this artery divides into a dorsal and a ventral vessel. The dorsal artery (fig. 37, Int.A._(1a)) passes to the right of the spleen, gives off the *splenic artery* (fig. 37; Spl.A.) to the spleen, and crossing the intestinal vessels₍₂₎ continues caudad along the posterior horn of the iliac loop; giving off numerous branches to the anterior horn and the posterior end of the intestine, and finally terminates on the dorsal side of the rectum. The ventral branch (fig. 37; Int.A._(1b)) passes ventrad and to the left of the spleen. Opposite the spleen it sends off the *posterior gastric artery* (fig. 37; P.Gas.A.), which crosses the cæca behind the corresponding vein, and supplies the posterior or cardiac end of the stomach. The main ventral intestinal vessel continues along the lower side of the posterior end of the intestine and terminates on the ventral side of the rectum.

Immediately after leaving the main trunk the *cœliac artery* (fig. 37; Cœ.A.) gives off the *right hepatic artery* (figs. 37 and 38; R.Hep.A.), which after crossing the cœliac and right portal sends off branches along the radicals of the right portal to the right lobe of the liver, and also gives off the *anterior gall-bladder artery*, which supplies the anterior third of the bladder, and does not anastomose with the posterior gall-bladder artery. Passing beneath intestinal vessels₍₁₎ the cœliac artery gives off a rather large *left hepatic artery* (figs. 37 and 38; L.Hep.A.), which follows along in front of the left portal, giving off numerous branches to the left lobe of the liver, which penetrate the liver with the large radicals of the common portal; while none of the branches of the left hepatic anastomose with similar branches of the right hepatic, several of them send up branches that supply the ventral portion of the stomach. Shortly after the branching off of the left hepatic from the

cœliac, intestinal artery₍₂₎ is given off to the right (fig. 37; Int.A.₍₂₎); passing caudad to the right of the corresponding vein it crosses under the ventral branches of intestinal vessels₍₁₎, the spleen, and the dorsal branches of intestinal vessels, and continuing caudad between the anterior and posterior horns of the iliac loop, supplies both of them. The cœliac artery proper separates into the *right* and *left pyloric cæca arteries*. The former (fig. 37; R.Cæ.A.) passes around the pylorus on pyloric cæcum₍₃₎, and bifurcates into a dorsal and a ventral branch; the ventral branch gives off a large branch which crosses under this cæcum, and continues caudad between cæcum₍₁₎ and cæcum₍₂₎, giving off branches to each. The *left pyloric cæca artery* (fig. 37; L.Cæ.A.) passes to the left of the pylorus between cæcum₍₄₎ and cæcum₍₅₎, giving off branches to each.

Portal System.—As in *Sebastodes* the 2 portals unite in forming a common portal, that breaks up into numerous radicals.

The *right portal* (fig. 37; R.Por.V.) has its origin from the right gastric, and intestinal vein₍₁₎. *Intestinal vein*₍₁₎ (fig. 37; Int.V.₍₁₎) arises from a dorsal and a ventral branch. The former (fig. 37; Int.V._(1a)) arises from the dorsal side of the rectum, and runs cephalad, parallel to the corresponding artery, but below it; receiving branches from the posterior end of the intestine and anterior horn of the iliac loop, it crosses intestinal vessels₍₂₎ and passes above and to the right of the spleen from which it receives the *splenic vein* (fig. 37; Spl.V.). Directly in front of the spleen the dorsal intestinal vein receives the ventral intestinal branch (fig. 37; Int.V._(1b)), which arises from the lower side of the rectum and passes forward along the ventral side of the corresponding artery. Curving around the ventral and left side of the spleen it receives two branches; the first one, which is the *posterior gastric vein* (fig. 37; P.Gas.V.) arises from the cardiac end of the stomach, and runs along in front of the posterior gastric artery; while the anterior vessel has its source from two branches, one coming from between pyloric cæca₍₁₎ and ₍₂₎, and the other from cæcum₍₃₎. After receiving these branches the ventral intestinal branch crosses over intestinal vessels₍₂₎, and in front of the spleen unites with

the dorsal intestinal branch to form main *intestinal vein*₍₁₎, which shortly joins the *right gastric vein* (fig. 37; R.Gas.V.) to form the *right portal*. This trunk (fig. 37; R.Por.V.) passes under intestinal artery₍₁₎, and when the right lobe of the liver is reached, sends off a branch to it, and anastomoses with the left portal to form the common portal. The branch to the right lobe of the liver receives the *gall-bladder vein* (fig. 37; G.Bl.V.), which drains the entire bladder, and receives a branch from a gland-like body marked G.

The *left portal vein* (fig. 37; L.Por.V.) has its origin from intestinal vein₍₂₎ and two pyloric cæca veins. *Intestinal vein*₍₂₎ (fig. 37; Int.V.₍₂₎) arising from the iliac loop passes cephalad below the corresponding artery, and after crossing under the dorsal branch of intestinal vein₍₁₎, the spleen, and the ventral branch of intestinal vein₍₁₎ it receives a vessel coming from the dorsal surface of pyloric cæcum₍₃₎, designated as the *right pyloric cæca vein* (fig. 37; R.Cæ.V.), and later the *left pyloric cæca vein* (fig. 37; L.Cæ.V.), which arises from between the fourth and fifth pyloric cæca. The left portal thus formed curves around on the dorsal surface of the liver and anastomosing with the right portal forms the *common portal trunk* (fig. 38; C.Por.V.), which gives off several terminal branches or radicals to the liver. Into this common portal is poured a rather large *ventral gastric vein* (fig. 38; V.Gas.V.), which may to some extent take the place of the absent left gastric vein found in *Ophiodon*.

The *dorsal aorta* presents no peculiarities, except that there are a great number of *spermatic arteries* (fig. 37; Sper.A.), usually 9 or 10.

Renal Portal System.—In the kidney there is a complete renal portal system. The *caudal vein* (fig. 37; Cau.V.) runs along the left dorsal surface of the kidney as the renal portal vein, giving off large *afferent renal veins* (fig. 37; A.Ren.V.) to each side; while the much smaller *efferent renal veins* (fig. 37; E.Ren.V.) return the blood to the *right cardinal*. This trunk receives, directly, 9 or 10 *spermatic veins* (fig. 37; Sper.V.) from the reproductive organs. The *intercostal veins* (fig. 37; Intc.V.), however, do not empty directly into the cardinal, but reach it through the efferent renal veins.

From the previous description it would seem that the vascular system of *Anoplopoma* exhibits many points of resemblance to the more generalized Teleosts. The external carotid, hyoidean, subclavian, hypobranchial, and coronary trunks appear to have a more primitive arrangement than is even shown in *Sebastodes*.

IX. GENERAL CONSIDERATIONS AND SUMMARY.

Since it is almost impossible to determine whether certain variations in the blood vessels are primitive or secondary it is not the intention of this paper to draw any conclusions as regards the classification of this group on the basis of the circulatory system, until after the anatomy of the other systems has been worked up. Still it is thought, although perhaps not practicable, that the vascular system might be used in the classification of families and genera, but could not be used in the discrimination of species. In the genus *Sebastodes* a great number of species were studied, both generalized and specialized, but no more variation was noticed in different species than could be found among individuals of the same species.

Several interesting anastomoses were noticed in both the arterial and venous systems. In *Ophiodon* we have in the region of the nasal sac a union of a branch of the internal carotid with one of the external carotid. The hyoidean artery anastomoses with the main stem of the external carotid to form the mandibular artery. A branch of the ventral artery joined one of the subclavian in the pectoral fin canal. The anterior spinal artery, a branch of the subclavian, united in the neural canal with the myelonal artery, a branch of the internal carotid. Two gall-bladder arteries unite on the surface of the bladder. Usually the posterior mesenteric artery communicates with intestinal artery₍₁₎, and there are connecting arteries between the right pyloric cæca artery and intestinal artery₍₁₎. In *Sebastodes* the two anterior spermatic arteries unite with the posterior or spermatic artery proper. In *Hexagrammos* the two hepatic arteries anastomose. In *Anoplopoma* the hyoidean arteries anastomose with the pseudobranchial arteries, and the hypobranchial arteries unite with the anterior ventral artery. Among the veins in *Ophiodon* there is an anastomosis under the nasal

sac of a branch of the internal jugular with one of the external jugular. A sinus-like vessel connects the two internal jugulars in the eye-muscle canal. A small vein connects the posterior encephalic veins directly behind the cerebellum. The ventral intercostal veins anastomose dorsally with the main intercostal veins. The gall-bladder veins unite on the surface of the bladder, and there are connecting vessels between the right pyloric cæca vein and intestinal vein₍₁₎. There is always some communication between the two portals: either they terminate in a common portal as is the case with *Sebastodes* and *Anoplopoma*, or terminal branch (a) of the left portal unites with the right portal as in *Hexagrammos*, or else there is a connecting vein in the neighborhood of the spleen as in *Ophiodon* and *Scorpenichthys*. If a posterior mesenteric vein is present as in *Ophiodon* and *Scorpenichthys* there is a grand anastomosis on the posterior or cardiac end of the stomach of branch Z of the posterior mesenteric with the right, left, and posterior gastric veins; and branch Y of the posterior mesenteric, usually, anastomoses with intestinal vein₍₁₎. The anterior spermatic veins in *Sebastodes* unite with the posterior or spermatic vein proper, and in *Scorpenichthys* the left gastric vein anastomoses with the ventral gastric vein.

In all the specimens studied there was the so-called choroid gland in the eye, a double vaso-ganglion or retia mirabilia, and a double retia mirabilia is also present in the air-bladder of *Sebastodes*.

The arrangement of the vascular and the blood vessels in the pseudobranchial filaments is essentially the same as in the branchial filaments, and it seems reasonable to suppose that the arterial blood for the eye receives additional oxygen in its course through the pseudobranchial capillaries.

Summary of the Arteries.—The carotids in all species studied, but *Anoplopoma*, rise from a common trunk, which soon separates into the external and internal carotids. In *Anoplopoma* each of the carotids rises directly from the first efferent branchial artery. In every case the internal carotid divides into the orbito-nasal and encephalic arteries. In all the genera but *Anoplopoma* the main stem of the external carotid

unites with the hyoidean artery to form the mandibular artery, but in this genus the hyoidean artery branches in the region of the preopercle. The ventral fork passes through a foramen in front of the preopercle to become the mandibular artery; while the dorsal fork passes along the inner surface of the hyomandibular and anastomoses with the pseudobranchial artery. Usually the pseudobranchial artery has its origin from the main stem of the external carotid (facialis-mandibularis) in the facial region, but with *Anoplopoma* the pseudobranchial artery rises from the external carotid close to its origin from the first efferent branchial artery; in fact it might be said to rise with the external carotid from the first efferent branchial artery, being fully as large as the carotid. An ophthalmic or efferent pseudobranchial artery always rises from the efferent pseudobranchial arteries, which supplies only the choroid coat of the eye. In *Ophiodon* the ventral artery rises from the ventral union of the second and third pairs of efferent branchial arteries; while in the other genera it comes from the union of the second efferent vessels. This artery in *Anoplopoma* is a short vessel barely reaching the pelvic bones; the supply for the ventral fin region comes from the subclavian. In all the genera but *Anoplopoma*, the pharynx artery, from which the coronary rises, has its source directly from one of the second or third efferent branchial arteries, but in this genus it rises from the ventral artery. There is always a distinct circulus cephalicus formed by the union of the encephalic, internal carotid, common carotid, first efferent branchial, and the first epibranchial arteries. Both pairs of epibranchials terminate in a common chamber from which the dorsal aorta, cœliaco-mesenteric, and subclavians have their origin; in some cases, however, this chamber is simply an opening between the aorta and the cœliaco-mesenteric. The dorsal aorta is essentially the same in all the genera; passing caudad beneath the vertebral column it gives off the renal and spermatic arteries to the kidney and the reproductive organs, the neural, hæmal, and intercostal arteries to the body wall, and finally terminates in the caudal fin. The subclavian arteries are practically the same in all the forms studied; they may arise from a single trunk or separately as was de-

scribed under *Ophiodon*, or they may arise from the dorsal aorta as in *Anoplopoma*. In the case of *Anoplopoma* a rather large hypobranchial artery is given off, which anastomoses with the anterior ventral artery, and the right hypobranchial sends off the posterior ventral artery for the ventral fin region. The coeliac artery always supplies the pyloric cæca. With *Ophiodon*, *Sebastodes*, and *Anoplopoma* it is the source of the left hepatic artery, and in *Ophiodon*, *Hexagrammos*, and *Anoplopoma* it gives off intestinal artery₍₂₎. From the mesenteric artery, intestinal artery₍₁₎, the splenic and 2 gastric arteries have their origin. In *Hexagrammos* and *Scorpenichthys* the right gastric is the source of the left hepatic artery, and in *Sebastodes* it is the source of the right spermatic and the anterior air-bladder arteries, the left spermatic artery coming from the left gastric artery. In *Scorpenichthys* the entire intestinal supply comes from the mesenteric artery.

Summary of the Veins. — The jugular and its branches are essentially the same in all the species studied, receiving the mandibular, hyoidean, maxillary, orbito-nasal, ophthalmic, eye-muscle, and encephalic veins. In addition to the main inferior jugular and the left fork there are additional veins from the pharynx region in *Sebastodes*, *Scorpenichthys*, and *Anoplopoma*, which empty into the precava. Considerable variation is shown in the subclavian veins. There is always an external and an internal subclavian, and in *Scorpenichthys* there are several internal subclavians. Ordinarily the internal subclavian breaks up in the corresponding fork of the kidney, and the external subclavian empties into the precava, but in *Scorpenichthys* the external subclavian also breaks up in the kidney, while in *Anoplopoma* the external subclavian appears to penetrate the scapula foramen with the corresponding artery, uniting with the internal vein to form a common trunk, which breaks up in the kidney. Usually there are 2 ventral veins of equal size, but in *Ophiodon* one of them is often much the larger, draining the entire ventral fin region. There is always a distinct renal portal system. The caudal vein arises in the tail and passing forward in the hæmal canal below the aorta, receives the neural and hæmal veins, and upon entering the kidney, usually, bifurcates

into the renal portal veins. With *Sebastodes* these veins extend much further cephalad than in the other genera, and in *Ophiodon* and *Scorpaenichthys* the caudal vein receives the posterior mesenteric vein immediately after entering the kidney. It is of interest to note in connection with the posterior mesenteric vein, that in 2 other genera of the Cottoids, namely, *Calycilepidotus* and *Enophrys*, this vessel was absent. The right cardinal always arises in the caudal end of the kidney and drains the entire kidney, while the left cardinal drains only a portion of the left lobe of the kidney. The intercostal and the anterior neural veins break up in the kidney. The spermatic veins vary greatly in size, number, and position; with the female they arise from numerous branches, passing along the lateral surfaces of the ovaries; while in the male these branches come from the inside of the testes, and the spermatic veins terminate in the right cardinal or the renal portal veins. The cardinals and jugulars always unite on the ventral surface of their respective lobe of the kidney to form the precava, which pass around the œsophagus and terminate in the sinus venosus. There is always a distinctive hepatic portal system, which takes its origin from a right and a left portal vein. Usually the left portal vein has its source from 2 pyloric cæca veins, an intestinal, and a few ventral gastric veins. In *Scorpaenichthys* it receives the entire intestinal supply. The right portal ordinarily arises from a right gastric, an intestinal, and a splenic vein; in *Scorpaenichthys* no intestinal vein is received; while in *Sebastodes* the right gastric branch receives the additional anterior air-bladder vein. In *Ophiodon*, always, and in *Scorpaenichthys*, usually, the 2 portals have no connection within the liver; while with *Hexagrammos* a branch of the left portal anastomoses with the right portal; and in *Sebastodes* and *Anoplopoma* the 2 portals and several minor vessels empty into and form a common portal. As in other vertebrates the portals break up into venous capillaries within the liver, and become collected by 2 hepatic veins, which unite in a hepatic sinus before emptying into the sinus venosus. An interesting vein in *Ophiodon* and *Scorpaenichthys* is the left gastric vein, which arises from the left side of the stomach and empties directly into the precava. With the

other genera this region is drained by enlarged ventral gastric veins, that empty into the left portal.

X. BRIEF SYNONYMY OF THE BLOOD VESSELS.

1. *Afferent branchial artery*, A.Br.A. Branches of the branchial artery, Monroe; Rameau (3), C. & V. Kiemenarterien, Hyrtl, Müller, and Stannius; Arterie branchiali, Emery; Arteria branchiales, McKenzie; Afferent branchial arteries, Parker; Kiemenarterien, V. & Y.¹

2. *Afferent filament arteries*, A.Fil.A. Une branche (*n*) à chacun de ces feuillets, C. & V. Ast der Kiemenarterie, Müller; Desc. by Stannius; (*e*) fig. 318, Owen; Branches of the afferent artery, Parker; Desc. V. & Y.

3. *Afferent renal veins* or *Advehent renal veins*, A.Ren.V. Venæ renalis advehens, Stannius; Vena aveente renale, Emery; Vena renalis advehens, McKenzie; Afferent renal veins, Parker.

4. *Air-bladder retia mirabilia artery* or *Anterior air-bladder artery*, A.Bl.A. Desc. Stannius; Branch of celiac to air-bladder, Owen; Desc. and fig. Emery; Desc. McKenzie; Artery to rete mirabile, Parker; Arterie der Schwimmblase, V. & Y.

5. *Air-bladder retia mirabilia vein* or *Anterior air-bladder vein*, A.Bl.V. Desc. Stannius; fig. Emery; Vessels from rete mirabile, Parker; Schwimmblasenvene, V. & Y.

6. *Auricle*, Aur. Oreillete, C. & V. Vorkammer, Müller, Stannius, and V. & Y. Auricle, Owen and Parker; Atrio, Emery; Atrium, McKenzie.

7. *Bulbus arteriosus*, B.Art. Bulbe (*γ*), C. & V. Bulbo aortico, Emery; Bulbus arteriosus, Hyrtl, Müller, Stannius, Owen, McKenzie, Parker, and V. & Y.

8. *Caudal artery*, Cau.A. Caudal aorta, Hyrtl; Arteria caudalis, Müller, Stannius, and McKenzie; Caudal artery, Parker; Bauchorta, V. & Y.

9. *Caudal vein*, Cau.V. Veins from the tail, Monroe; Vena caudalis, Hyrtl. Müller, and Stannius; Vena cardinalis, Owen;

¹Abbreviations C. & V. stand for Cuvier and Valenciennes, V. & Y. for Vogt and Yung, and Desc. for described.

Vena codale, Emery; Vena caudalis, McKenzie; Caudal vein, Parker.

10. *Celiac artery*, Cœ.A. An artery like unto our cœliac, Monroe; Arteria cœliaca, Hyrtl and Stannius; Cœliac, Owen; A. Mesenterica inferiore Emery (?); Cœliac artery, Parker.

11. *Cœliaco-mesenteric artery*, Cœ.Mes.A. Arteria cœliaco-mesenterica, Hyrtl, Stannius, and McKenzie; Arteria cœliaca, Emery (?); La grande artère aux viscères (π), C. & V. Cœliaco-mesenteric artery, Owen; Cœliaco-mesenteric artery, Parker; Baucharterie, V. & Y.

12. *Common carotid arteries*, C.Car.A. Les artères de la tête (s), C. & V. Carotis communis, Stannius; Kopfarterien, V. & Y. Common carotid arteries, Parker.

13. *Coronary artery*, Cor.A. Coronary artery, Monroe; Fig. C. & V. Kranzarterie, Hyrtl and Müller; Coronary artery, McKenzie and Parker.

14. *Coronary veins*, Cor.V. Coronary veins, Monroe and Parker.

15. *Dorsal aorta*, D.Ao. Trunk of descending aorta, Monroe; Aorte, C. & V. Aorta, Hyrtl, Müller, Owen, Emery, V. & Y. Aorta decedens, McKenzie; Dorsal aorta, Parker.

16. *Efferent branchial arteries*, E.Br.A. Branchial veins, Monroe; La grande veine de la branchie (λ), C. & V. Kiemenvenen, Hyrtl, Müller, Stannius, and V. & Y. Vene branchiali, Emery; Venæ Branchiales, McKenzie; Efferent branchial arteries, Parker.

17. *Efferent filament arteries*, E.Fil.A. Une veine branchiale (ϑ), C. & V. Ast der Kiemenvene, Müller; Desc. Stannius; (d) fig. 318, Owen; Desc. McKenzie and V. & Y. Branches of the efferent arteries, Parker.

18. *Efferent renal veins* or *Revehent renal veins*, E.Ren.V. Venæ renales revehentes, Stannius; Vena reveente, Emery.

19. *Encephalic artery* or *Brain artery*, Enc.A. Zweige zum Hirn, Müller; Hirnarterie, Stannius; Encephalic arteries (3), McKenzie, Cerebral artery, Parker; Hirnarterie, V. & Y.

20. *Encephalic vein*, Enc.V. Desc. by Stannius; Desc. and fig. by Emery; Anterior cerebral vein, Parker.

21. *Epibranchial arteries*, Epbr.A. (μ), C. & V. Aortenwurzeln, Hyrtl; Venæ branchiales communes, Müller; Epibranchial arteries, Parker.

22. *External carotid arteries* or *posterior carotid arteries*, E.Car.A. Arteries sent to jaws, Monroe (?); Carotis externa, Hyrtl and McKenzie; Carotis posterior, Müller and Stannius; Carotids, Owen; Carotide posteriore, Emery; Posterior carotids, Parker; Gesichtsarterie and Arteria facialis, V. & Y.

23. *External jugular or facial veins*, Ex.J.V. Desc. by Stannius; Anterior facial veins, Parker; Gesichtsvene or Vena facialis, V. & Y.

24. *Hæmal arteries*, Hae.A. Hæmal arteries, Owen and McKenzie; Fig. C. & V. and V. & Y.

25. *Hæmal veins*, Hae.V. Hæmal veins, Owen and McKenzie; Fig. C. & V. and V. & Y.

26. *Hepatic sinus*, Hep.S. and *Hepatic veins*, Hep.V. Venae cava Hepaticae, Monroe; Les venes du foie, C. & V. Lebervene, Müller and Stannius; Hepatic vein, Owen and McKenzie; Hepatic veins and sinus, Parker; Lebervene, V. & Y.

27. *Hyoidean artery*, Hyo.A. Fig. C. & V. Arteria hyoideo-opercularis, Müller; Arteria hyoidea, Stannius; Hyo-opercular artery, Owen; Arteria, ioidea, Emery; Hyoidean artery, Parker.

28. *Hyoidean vein*, Hyo.V. Vena ioidea, Emery; Hyoidean sinus, Parker (?).

29. *Hypobranchial artery*, Hypobr.A. Fig. by Monroe; Desc. by McKenzie; Hypobranchial artery, Parker.

30. *Inferior jugular vein*, I. J. V. External jugular vein, Monroe; Vena jugularis inferior, Müller, Stannius, and McKenzie; Inferior jugular vein, Parker.

31. *Inner iris vein*, I.Ir.V. Die innere Vene der Iris, Müller.

32. *Intercostal arteries*, Intc.A. Arteriæ intercostales, Hyrtl, Müller and Stannius; Intercostals, Owen and McKenzie; Intervertebrale æste V. & Y.

33. *Intercostal veins*, Intc.V. Venæ intercostales, Müller and McKenzie; Intercostal veins, Parker.

34. *Internal carotid artery*, I.Car.A. Retrograde artery (ζ), Monroe (?); Carotis anterior, Müller and Stannius; Carotis interna, Hyrtl and McKenzie; Carotide anteriore, Emery; Anterior carotid artery, Parker; Einen tieferen Stamm, V. & Y.

35. *Internal jugular veins*, In.J.V. Vena jugularis interna, Müller.

36. *Internal subclavian arteries*, I.Sub.A. Arteria branchialis, Stannius; Branchial artery, Parker.

37. *Intestinal artery* (1), Int.A. (1). Arteriæ intestinales mesenterica, Stannius; Posterior mesenteric artery, Owen; Mesenterica superiore, Emery (?); Mesenteric artery, McKenzie; Dorsal intestinal artery, Parker (?); Duodenalarterie, V. & Y. (?)

38. *Intestinal artery* (2), Int.A. (2). Fig. C. & V. Arteriæ intestinales cœliaco, Stannius; Ventral intestinal artery, Parker (?); Darmarterie, V. & Y. (?)

39. *Intestinal vein* (1), Int.V. (1). Darmvene, Müller; Desc. Stannius; Fig. Emery; Mesenteric vein, McKenzie; Dorsal intestinal vein, Parker (?); Darmvene, V. & Y. (?)

40. *Intestinal vein* (2), Int.V. (2). Ventral intestinal vein, Parker (?)

41. *Iris artery* or *Ophthalmic minor artery*, Ir.A. Arteria ophthalmica minor, Müller; Desc. Stannius.

42. *Iris vein* or *Ophthalmic minor vein*, Ir.V. Die äussere Vene der Iris, Müller; Die Vene der Iris, Stannius.

43. *Jugular vein*, J.V. Internal jugular vein, Monroe; Les veines de la tête (ω), C. & V.; Vena jugularis superior, Müller; Vena vertebralis anterior, Stannius; Vena jugularis, Owen; Vena giugulare, Emery; Anterior cardinals, McKenzie; Jugular vein, Parker; Jugularvene, V. & Y.

44. *Lateral arteries*, Lat.A. Arteria lateralis, Stannius; Lateral arteries, McKenzie.

45. *Lateral veins*, Lat.V. Lateral veins, McKenzie.

46. *Left cardinal vein*, L.Car.V. Abdominal or vena cava, Monroe; Les veines des reins (ϕ), C. & V.; Vertebralvene, Müller; Vena vertebralis posterior, Stannius; Vena cardinalis, Owen; Vena cardinale, Emery; Left cardinal vein, McKenzie and Parker; Linke cardinalvene, V. & Y.

47. *Left gastric artery*, L.Gas.A. Fig. C. & V. and V. & Y. Anterior gastric artery, Parker (?)

48. *Left gastric vein*, L.Gas.V. Anterior gastric vein, Parker (?)

49. *Left hepatic artery*, L.Hep.A. Small artery resembling the hepatic artery, Monroe; Desc. by C. & V. and Müller; Arteriæ hepaticæ, Hyrtl and Stannius; Hepatic artery, McKenzie; Left hepatic artery, Parker; Leberarterie, V. & Y.

50. *Mesenteric artery*, Mes.A. An artery resembling our superior mesenteric artery, Monroe; Arteria mesenterica anterior, Hyrtl and Stannius; Arteria celiaca, Emery (?); Mesenteric artery, Parker; Baucharterie, V. & Y. (?).

51. *Myelonal artery*, My.A. Myelonal artery, Parker.

52. *Myelonal vein*, My.V. Not vena neuralis of Owen; Myelonal vein, Parker.

53. *Neural arteries*, Neu.A. Arteria spinales, Hyrtl; Neural arteries, McKenzie; Spinal arteries, Parker.

54. *Neural veins*, Neu.V. Neural veins, Owen and McKenzie; Spinal veins, Parker.

55. *Nutrient branchial arteries*, N.Br.A. Nutrient branchial arteries, Parker.

56. *Nutrient branchial veins*, N.Br.A. Venæ nutritiæ der Kiemenbogen, Müller; Venæ nutritiæ, Stannius and Owen; Nutrient branchial veins, Parker.

57. *Nutrient filament arteries*, N.Fil.A. Bronchialarterien, Müller; Arteria bronchialis, Stannius; Arteriæ nutritiæ, Owen.

58. *Nutrient filament veins*, N.Fil.V. Bronchialvenen, Müller; Vena bronchiales, Stannius.

59. *Ophthalmic artery* or *Efferent pseudobranchial artery*, Oph.A. Arteria ophthalmica magna, Müller and Stannius; Ophthalmic artery, Owen; Desc. and Fig., Emery; Ophthalmica magna, McKenzie; Ophthalmic artery, Parker; Efferent pseudobranchial artery, Allis.

60. *Ophthalmic vein*, Oph.V. Vena ophthalmica magna, Müller and Stannius; Desc. and Fig. Emery.

61. *Optic or Retina artery*, Opt.A. Die Gefäße der Retina und der Hallenschen Gefäße, Müller; Arteria ottalmica, Emery (?); Optic artery, Allis.

62. *Orbito-nasal artery*, O.N.A. Zweige zu den Augenmuskeln und zur Nase, Müller; Arteria etmoidale, Emery; Augenarterie, V. & Y.

63. *Orbito-nasal vein*, O.N.V. Vena etmoidale, Emery; Orbital sinus, Parker.

64. *Pharynx artery*, Phar.A. Pericardial artery, Parker (?).

65. *Posterior air-bladder artery*, P.A.Bl.A. Vena vescicale posteriore, Emery.

66. *Posterior encephalic vein*, P.Enc.V. Desc. by Emery; Posterior cerebral vein, Parker.

67. *Posterior or left portal vein*, L.Por.V. La veine porte (l), C & V. Pfortaderstamm, Müller and Stannius; Portal trunk, Owen; Portal vein, McKenzie; Hepatic portal and Portal vein, Parker; Pfortader, V. & Y.

68. *Precaval vein* or *Ductus cuvieri*, Prec.V. Desc. and figured by Monroe; Trunci transversi, Stannius; Precaval vein, Owen; Tronco di Cuvier, Emery; Ductus cuvieri, McKenzie; Precaval vein, Parker; Ductus cuvieri, V. & Y.

69. *Pseudobranchial artery* or *Afferent pseudobranchial artery*, Ps.A. Part of Arteria hyoideo-opercularis, Müller; Part of Arteria hyoidea, Stannius; Part of Hyo-opercular, Owen; Part of Arteria ioidea, Emery; Pseudobranchial artery, Parker; Afferent pseudobranchial artery, Allis.

70. *Pyloric cæca arteries*, R.Cæ.A. Fig. C. & V. Desc. by Stannius, Parker, and V. & Y.

71. *Pyloric cæca veins*, R.Cæ.V. Fig. C. & V. Desc. by Stannius and V. & Y.

72. *Renal Arteries*, Ren.A. Arteria renales, McKenzie; Renal arteries, Parker; Nieren arterienzweige, V. & Y.

73. *Renal portal vein*, Ren.P.V. Vena renalis advehens, Stannius; Veine porte rénale, Jourdain; Vena aveente renale, Emery; Vena renalis advehens, McKenzie; Renal portal vein, Parker.

74. *Right cardinal vein*, R.Car.V. Vena vertebralis posterior dextra, Stannius; Venæ cardinales, Owen; Vena cardinale, Emery; Right cardinal vein, McKenzie and Parker; Rechte cardinalvene, V. & Y.

75. *Right gastric artery*, R.Gas.A. Desc. Müller, Stannius, and McKenzie; Gastric artery, Owen; Fig. and Desc. Emery; Dorsal gastric artery, Parker (?); Magenarterie, V. & Y.

76. *Right gastric vein*, R.Gas.V. Desc. Stannius; Fig. Emery; Gastric vein, McKenzie; Anterior lieno-gastric vein, Parker (?); Desc. and Fig. V. & Y.

77. *Right hepatic artery*, R.Hep.A. Einen für jeden Leberlappen, Müller; Arteriæ hepaticæ, Stannius, Right hepatic artery, Parker; Leberarterie, V. & Y.

78. *Sinus venosus*, Sin.Ven. Sinus veineux, C. & V. Sinus venosus, Stannius, Hyrtl, Owen, McKenzie, and Parker; Sinus communis, Müller; Venensinus, V. & Y.

79. *Spermatic artery*, Sper.A. Fig. C. & V. Genitalarterie, Müller and V. & Y. Desc. Stannius; Fig. Emery and C. & V. Genital artery, McKenzie; Spermatic artery, Parker.

80. *Spermatic vein*, Sper.V. Les veines des organes de la génération (φ), C. & V. Genitalvenen, Müller and V. & Y. Desc. Stannius; Fig. Emery; Genital veins, McKenzie; Spermatic veins, Parker.

81. *Splenic artery*, Spl.A. Fig. C. & V. and Emery; Desc. Stannius and Owen; Splenic artery, McKenzie and Parker; Desc. and Fig. by V. & Y.

82. *Splenic vein*, Spl.V. Fig. C. & V. and Emery; Desc. Stannius; Vein from spleen, Owen; Splenic vein, McKenzie and Parker; Desc. and Fig. V. & Y.

83. *Subclavian artery*, Sub.A. Subclavian artery, Monroe, Owen, McKenzie, and Parker; Arteria subclavia, Müller, Hyrtl, and Stannius; Arterie ascellari, Emery; Schulterarterie, V. & Y.

84. *Subclavian veins* (1), (2), and (3), Sub.V. (1) to (3). Subclavian vein, Monroe and Parker; Vena subclavia, Stannius; Includes the branchial vein of Stannius and Parker; Schultervene, V. & Y.

85. *Thyroid artery*, Thyr.A. Thyroid artery, McKenzie.

86. *Urinary bladder artery and vein*, Ur.B.A. and Ur.B.V. Fig. C. & V. and V. & Y.

87. *Ventral aorta or Branchial artery*, V.Ao. Branchial artery, Monroe and Owen; L'artère branchiale (ϵ), C. & V. Arteria branchialis, Müller; Kiemenarterienstamm, Stannius; Cardiac aorta, Huxley; Truncus arteriosus, McKenzie; Tronco dell'aorta, Emery; Gemeinsame Kiemenarterie, V. & Y.

88. *Ventral artery*, Ven.A. Ramus epigastricus decendens, Müller (?); Arteria epigastrica, Stannius; Fig. C. & V. Artery supplying the pelvic fins, Parker.

89. *Ventral intercostal arteries*, V.Intc.A. Fig. C. & V. Arteriæ intercostales ventrales, Müller.

90. *Ventral intercostal veins*, V.Intc.V. Fig. C. & V. Vena intercostales ventrales, Müller.

91. *Ventral veins*, Ven.V. May be homologous to the epigastric veins of Müller and Stannius.

92. *Ventricle*, Ven. Ventricule, C. & V. Herzkammer, Müller, Stannius, and V. & Y. Ventricolo, Emery; Ventricle, Owen, McKenzie, and Parker.

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XII. EXPLANATION OF THE PLATES.

All figures were drawn from actual dissections. Fig. 1 was compiled from the dissections of three or four specimens, the others from a single specimen.

The arteries are colored red and the veins blue. A vessel drawn in dotted lines signifies that it passes in or behind a bone, muscle, or organ.

PLATE I.

Ophiodon elongatus; Blue cod.

- FIG. 1. Represents a general lateral view of the vascular system. The hyoid vessels are cut and the arch moved caudad from its natural position to show the deeper branchial vessels, and a considerable part of the caudal portion of the body between the vent and the caudal fin is left out.
2. Dorsal view of an injected gill or branchial filament. Meshes of the capillary network are diagrammatic and are greatly enlarged. Injected with Hoyer's chrome yellow gelatin mass. Natural size.
 3. Dorsal view of a pseudobranchial filament. Efferent vessels in yellow. Its network is also greatly enlarged. Injected as Fig. 2. Natural size.
 4. Lateral view of a portion of the efferent pseudobranchial filament artery. Injected as Fig. 2. Leitz 3. Oc. 1. $\times \frac{1}{2}$.
 5. Represents a ventral view of the union of the efferent branchial arteries to form the main arterial trunks, and also the large venous trunks emptying into the precaval veins. Only the left dorsal branchial retractor muscle is indicated. A 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
 6. A portion of the viscera from the left and dorsal side. Opposite side of the stomach shown from Fig. 1. 40 lb. *Ophiodon*, $\times \frac{1}{4}$.
 7. Origin of the caudal vein from the ventral side, showing its relations with the lymphatic system. 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
 8. Deeper dissection of Fig. 7. showing the ending of the caudal artery.
 9. Anterior view of a caudal vertebra, showing the caudal trunks in section. 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
 10. General lateral view of the blood supply to the kidney, testes, and urinary-bladder of a 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
 11. Dorsal dissection of the liver to show the main trunks. Portal system in blue and hepatic system drawn in outline. 20 lb. *Ophiodon*, $\times \frac{1}{2}$.

PLATE II.

Ophiodon elongatus; Blue cod.

- Fig. 12. Represents a general ventral view of the head region, including the ventral or pelvic fins. Hyoid arch and genio-hyoideus muscle entirely removed from the left side. Pectorals also not shown. 40 lb. *Ophiodon*, $\times \frac{1}{2}$.
13. Eye muscles from the left side. 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
14. Shows the blood supply to the inner surface of the right pectoral fin. 40 lb. *Ophiodon*, $\times \frac{1}{2}$.
15. Represents a dorsal dissection at the level of the floor of the brain case. To show the blood supply for the eye, eye muscles, and brain. Floor of the brain case removed, and the trigeminal-facialis trunks are shown on the right side. 20 lb. *Ophiodon*, $\times \frac{1}{2}$.
16. General lateral view in the region of the left head kidney. To show the blood supply for the posterior part of the brain and the cord. $\times \frac{1}{2}$.

PLATE III.

Ophiodon elongatus; Blue cod.

Hydrolagus collicii; Chimæra (Fig. 26).

- FIG. 17. Represents the blood supply to and from the nasal sac, as seen from the right side. Anterior part of the eye shown in outline. 40 lb. *Ophiodon*, $\times 2$.
18. Same as 17. Nasal sac in outline, to show the veins leaving the inner side of the sac.
19. Dissection of the right eye from the inside. The sclerotic coat and silver layer of the choroid are removed to show the large choroid sinus, the double rete mirabile or choroid gland, and the iris vein, all of which run in the vascular layer of the choroid coat. 20 lb. *Ophiodon*, natural size.
20. Same eye, but deeper dissection to show the choroid artery and its rete mirabile.
21. Frontal section through the retina and choroid coats, showing the choroid artery, the choroid sinus, and the retina artery in section. 20 lb. *Ophiodon*, natural size.
22. Shows an inside view of the right eye. A sagittal incision was made nearly through an injected eye and the three coats were folded to the right. The entire course of the retina artery from its entrance with the optic nerve until it ends on the lens is distinctly shown. 15 lb. *Ophiodon*, $\times \frac{1}{2}$.
23. General lateral view of the blood supply to and from the brain. 15 lb. *Ophiodon*, natural size.
- 23a. Blood vessels to and from the auditory organs. 30 lb. *Ophiodon*, natural size.
24. General dorsal view of the vascular supply of the same brain as Fig. 23. Cranial nerves and anterior encephalic veins shown only on the right side.
25. Same brain as above from the ventral side. Cranial nerves not shown on the right side.
26. General lateral view of the main branchial vessels of *Hydrolagus collicii*, Chimæra. Inserted to show the wide variation in the carotid arteries. $\times \frac{1}{2}$.

PLATE IV.

Hexagrammos decagrammus; Sea trout (Figs. 27 and 28).

Scorpaenichthys marmoratus; Cabezon (Figs. 29 and 30).

Sebastes auriculatus; Rock cod (Figs. 31 and 34).

Sebastes flavidus; Rock cod (Figs. 32 and 33).

- FIG. 27. Represents a general lateral view of the viscera of a 12 in. *Hexagrammos*. The organs are greatly spread out, in order to better display their blood vessels. $\times \frac{1}{2}$.
28. Same specimen as above, showing the opposite or left side of the stomach.
29. General lateral view of the viscera of a 15 in. *Scorpaenichthys*. The organs are well spread out to show their blood supply and the liver is not figured. $\times \frac{1}{2}$.
30. Same specimen as above, showing the left or opposite side of the stomach, and including the liver and the inner surface of the left pectoral fin. Hepatic system shown in dotted lines.
31. Represents a general lateral view of the viscera of a 12 in. *Sebastes auriculatus*. Body tilted to show the ventral surface of the kidney, and all the organs spread out so as to best reveal their blood vessels. Notice the spermatic vein emptying directly into the left precaval vein. $\times \frac{1}{2}$.
32. A portion of the viscera, showing the blood supply for the left side of the stomach (opposite side from Fig. 31), and the liver of a 10 in. *Sebastes flavidus*. This species, though one of the most generalized of the genus, has a system of blood vessels identical with *S. auriculatus*, which is one of the most specialized. $\times \frac{1}{2}$.
33. Shows the blood supply to the gall-bladder and to a gland-like body. *Sebastes flavidus*, $\times \frac{1}{2}$.
34. Shows a variation in the vascular system to the gall-bladder. *Sebastes auriculatus*, $\times \frac{1}{2}$.

27

29

PLATE V.

Anoplopoma fimbria; Black cod.

- FIG. 35. Represents general lateral view of the principal trunks in the head region of *Anoplopoma*, $\times \frac{1}{2}$.
36. Shows general ventral view of the head region, including the pectoral and ventral fins of *Anoplopoma*. Ventral musculature and œsophagus removed to show the heart and union of the epibranchial arteries to form the dorsal aorta, cœliaco-mesenteric, and subclavian arteries. $\times \frac{1}{2}$.
37. View of the viscera of *Anoplopoma* from the left and dorsal side. $\times \frac{1}{2}$.
38. A portion of the viscera of *Anoplopoma* from the left and ventral side. $\frac{1}{2}$.

ON
QNA
Oph.A.
Hyo.V.
A
Man.A.

PLATE VI.

Heart of Ophiodon elongatus.

FIG. 39 is from a photograph of the posterior half of a large *Ophiodon's* heart, looking inward and caudad. This heart had previously been injected with a gelatin mass and hardened in formalin, and the cut was made directly between the anterior and posterior auriculo-ventricular valves.

× 4.

40. As above, is a photograph of the ventral side of a large *Ophiodon's* heart. A portion of the ventral wall of the ventricle had been removed to the depth of the central cavity to show the semi-lunar and auriculo-ventricular valves. × 2.

Abbreviations used. — Aur., Auricle. A.V.O., Auriculo-ventricular opening. A.V.V., Auriculo-ventricular valves. B.Art., Bulbus arteriosus. C.Art., Conus arteriosus. C.C.V., Central cavity of the ventricle. C.T., Connective tissue. L.F., Longitudinal folds or ridges. M.L., Muscular layer. S.A.O., Sinu-auricular opening. S.A.V., Sinu-auricular valves. S.V., Semi-lunar valves. S.Ven., Sinus venosus. T.C.A., Trabeculæ carnæ auricle. T.C.V., Trabeculæ carnæ ventricle. V.Ao., Ventral aorta. Ven., Ventricle.

Text-fig. 1. — Represents a transverse section through the auricle and ventricle of *Ophiodon elongatus*. This section was made through one of the auriculo-ventricular valves. Camera lucida. Leitz No. 2 obj. with lower lens removed.

Text-fig. 2. — Camera drawing of transverse section through the region of the conus arteriosus. Same obj. as above.

Abbreviations used. — Aur., Auricle. A.V.V., Auriculo-ventricular valve. C.T., Connective tissue. E.M.F., Elastic muscle fibers. End., Endothelium. L.M., Longitudinal muscle fibers. S.V., Semi-lunar valves. T.M., Transverse muscle fibers. Ven., Ventricle.

XIII. REFERENCE LETTERS AND ABBREVIATIONS USED IN THE FIGURES.

The letter D or V prefixed to an abbreviation indicates dorsal or ventral; R or L, right or left; A or P, anterior or posterior; Ex or In, external or internal. A series of similar named vessels is numbered from cephalad to caudad.

A.A.	Anterior ampulla.
A.Aud.A.	Anterior auditory artery.
a to e.	Terminal branches or radicals of the left portal.
A.Bl.	Air-bladder.
A.Bl.A.	Anterior air-bladder or retia mirabilia artery.
A.Bl.V.	Anterior air-bladder or retia mirabilia vein.
A.Br.A.	Afferent branchial arteries.
Ab.V.S.	Abductor muscle of ventral spine.
A.Cer.A.	Anterior cerebral artery.
A.Cer.V.	Anterior cerebral vein.
Ad.Hym.	Adductor hyomandibularis.
Add.M.M.	Adductor mandibulæ muscles.
Ad.Pal.A.	Adductor palatine arch. M. adductor arcus palatini.
A.Fil.A.	Afferent filament arteries.
A.G.Bl.A.	Anterior gall-bladder artery.
A.G.Bl.V.	Anterior gall-bladder vein.
A.Int.A.	Anterior intestinal artery.
A.Int.V.	Anterior intestinal vein.
A.Ps.Fil.A.	Afferent pseudobranchial filament artery.
A.R.	Anal fin rays.
A.Ren.V.	Afferent or advehent renal veins.
A.Ret.M.	Arterial retia mirabilia of choroid gland.
Aud.A.	Auditory artery.
Aud.C.	Auditory capsule.
Aud.V.	Auditory vein.
Aur.	Auricle.
B.Art.	Bulbus arteriosus.
Br.A.	Branchial arches.
Br.M.A.	Dorsal branchial muscle arteries.
Br.O.A.	Branchiostegal arteries.
Br.R.	Branchiostegal rays.
Cæ.	Pyloric cæca.
Cæ _{(1) to (5)}	Five pyloric cæca of <i>Anoplopora</i> .
Camp.H.	Campanula Halleri.
Cau.A.	Caudal artery.
Cau.V.	Caudal vein.
C.C.A.	} Cranial cavity arteries.
C'.C'.A'.	
C''.C''.A''.	
C.Car.A.	Common carotid artery.
C.C.V.	} Cranial cavity veins.
C'.C'.V'.	
Cen.	Centrum.

Cer.	Cerebellum.
Cer.A.	Cerebellum artery.
Cer.H.	Cerebral lobes or hemispheres.
Chor.	Choroid coat of the eye.
Chor.A	Choroid arteries.
Chor.A. ⁽¹⁾	Superior choroid artery.
Chor.A. ⁽²⁾	Inferior choroid artery.
Chor.S.	Choroid sinus.
Chor.V.	Choroid veins.
Cil.B.	Ramus ciliaris brevis.
Cil.L.	Ramus ciliaris longus.
Cil.N.	Ciliary nerve.
C.L.Sin.	Caudal lymphatic sinus.
Cæ.A.	Cæliac artery.
Cæ.Mes.A.	Cæliaco-mesenteric artery.
Con.Art.	Conus arteriosus.
Cor.A.	Coronary artery.
Cor.V.	Coronary vein.
C.P.V.	Common portal vein. <i>Sebastodes</i> and <i>Anoplopoma</i> only.
C.R.	Caudal fin rays.
Cran.	Cranial wall.
C./V./	Connecting vein. <i>Ophiodon</i> and <i>Scorpaenichthys</i> only.
C.Ver.	Caudal vertebra.
D.Ao.	Dorsal aorta.
D.Br.R.M.	Dorsal branchial retractor muscle. Retractor arc. branch dorsalis of Vetter.
D.Chor.V.	Dorsal choroid vein.
Di.Op.M.	Dilator opercular muscle.
D.Lat.A.	Dorsal lateral arteries.
D.Lat.V.	Dorsal lateral veins.
D. & L.M.P.R.	Depressor and levator muscles of the pectoral rays.
D.L.V.	Dorsal lymphatic vessel.
D.M.A.R.	Depressor muscle, anal ray.
D.M.D.R.	Depressor muscle, dorsal ray.
D.O.M.	Dorsal oblique muscles of the branchial arches (3). Obliqui dorsales of Vetter.
D.R.	Dorsal fin rays.
D.S.	Dorsal spines.
E.A.	External ampulla.
E.Br.A.	Efferent branchial arteries.
E.Br.L.	External branchial levator muscles (4). Levatores arch. branch externi of Vetter.
E.Car.A.	External carotid artery.
E.Fil.A.	Efferent filament arteries.
Enc.A.	Encephalic artery.
Enc.V.	Encephalic vein.
Epbr.A.	Epibranchial arteries.
Epi.	Epiphysis.
E.Ps.Fil.A.	Efferent pseudobranchial filament arteries.

E.Ren.A.	Efferent renal or revehent renal veins.	
E.Sub.A.	External subclavian artery.	
Eth.	Ethmoid.	
Ex.J.V.	External jugular vein.	
Ex.R.A.	External rectus artery.	
Ex.R.M.	External rectus muscle.	
Ex.R.V.	External rectus vein.	
F.A.	Facial artery.	
Fal.P.	Falciform process.	
Fil.Net.	Branchial filament network.	
F.Man.A.	Facialis-mandibularis artery.	
F.Man.V.	Facialis-mandibularis vein.	
F.Max.A.	Facialis-maxillaris artery.	
F.Max.V.	Facialis-maxillaris vein.	
G.	Gland.	
G.B.	Gall-bladder.	
Ghs.A.	Geniohyoideus artery.	
Ghs.M.	Geniohyoideus muscle.	
Ghs.V.	Geniohyoideus vein.	
Gl.H.	Glossohyal.	
H.	Hypophysis.	
Hæ.A.	Hæmal arteries.	
Hæ.L.V.	Hæmal lymphatic vessels.	
Hæ.V.	Hæmal veins.	
Hep.S.	Hepatic sinus.	
Hep.V.	Hepatic vein.	
H.Kid.	Head kidney.	
H.S.	Hæmal spine.	
H.S.C.	Horizontal or external semicircular canal.	
Hyo.A.	Hyoidean artery.	
Hyoid.	Hyoid arch.	
Hyo.V.	Hyoidean vein.	
Hyp.	Hypural bone.	
Hypobr.A.	Hypobranchial artery.	
Hys.A.	Hyohyoideus inferior artery.	
Hys.M.	Hyohyoideus inferior muscle.	
Hys.S.M.	Hyohyoideus superior muscle.	
Hys.V.	Hyohyoideus inferior vein.	
I.Br.L.	Internal branchial levator muscles (2). Levatores arcuum branchialium interni of Vetter.	
I.Car.A.	Internal carotid artery.	
I.Ir.V.	Inner iris vein.	
I.J.V.	Inferior jugular vein.	
I.lob.V.	Interlobular veins.	
Inf.A.	Infundibular artery.	
Inf.L.	Hypoaria or inferior lobes.	
Inf.O.A.	Inferior oblique muscle artery.	
Inf.O.M.	Inferior oblique muscle.	
Inf.O.V.	Inferior oblique muscle vein.	

Inf.R.M.	Inferior rectus muscle.
In.H.	Interhyal.
In.J.V.	Internal jugular vein.
In.Man.M.	Intermandibularis muscle.
Int.	Intestine.
Int.A. ₍₁₎ .	Intestinal artery ₍₁₎ .
Int.A. _(1a) .	Dorsal branch of intestinal artery ₍₁₎ . In <i>Anoplopoma</i> .
Int.A. _(1b) .	Ventral branch of intestinal artery ₍₁₎ . In <i>Anoplopoma</i> .
Int.A. ₍₂₎ .	Intestinal artery ₍₂₎ .
Intc.A.	Intercostal arteries.
Intc.V.	Intercostal veins.
Int.R.A.	Internal rectus artery.
Int.R.M.	Internal rectus muscle.
Int.R.V.	Internal rectus vein.
Int.V. ₍₁₎ .	Intestinal vein ₍₁₎ .
Int.V. _(1a) .	Dorsal branch of intestinal vein ₍₁₎ . In <i>Anoplopoma</i> .
Int.V. _(1b) .	Ventral branch of intestinal vein ₍₁₎ . In <i>Anoplopoma</i> .
Int.V. ₍₂₎ .	Intestinal vein ₍₂₎ .
Ir.	Iris.
Ir.A.	Iris artery.
Ir.V.	Iris vein.
Ir.V. ₍₁₎ .	Ventral or minor iris vein.
I.Sub.A.	Internal subclavian artery.
I.Sub.A. ₍₁₎ .	Superficial branch of the internal subclavian artery.
I.Sub.A. ₍₂₎ .	Profundus branch of the internal subclavian artery.
J.L.O.	Jugular lymphatic opening.
J.V.	Jugular vein.
Kid.	Kidney.
L.	Liver.
Lat.A.	Lateral arteries.
Lat.V.	Lateral veins.
L.Cæ.A.	Left pyloric cæca artery.
L.Cæ.V.	Left pyloric cæca vein.
L.Car.V.	Left cardinal vein.
L.Cau.A.	Left caudal artery.
L.Cau.V.	Left caudal vein.
L.Gas.A.	Left gastric artery.
L.Gas.V.	Left gastric vein.
L.G.X.	Left gastric ramus of the vagus.
L.Hæ.L.V.	Longitudinal hæmal lymphatic vessel.
L.Hep.A.	Left hepatic artery.
L.Hep.A. ₍₁₎ .	Posterior or minor left hepatic artery.
L.Hep.V.	Left hepatic vein.
Lin.A.	Lingual artery.
Lin.V.	Lingual vein.
L.L.V.	Lateral lymphatic vessel.
L.M.A.R.	Levator muscles of the anal rays.
L.M.D.R.	Levator muscles of the dorsal rays.
L.Neu.L.V.	Longitudinal neural lymphatic vessel.

L.Op.M.	Levator opercular muscle.
L.Pal.A.	Levator palatine arch. Levator arcus palatini of Vetter.
L.Pal.A.A.	Levator of palatine arch artery.
L.P.Gas.A.	Left posterior gastric artery.
L.P.Gas.V.	Left posterior gastric vein.
L.Por.V.	Left portal vein.
L.Sper.A.	Left spermatic artery. In <i>Sebastodes</i> .
L.Sper.V.	Left spermatic vein. In <i>Sebastodes</i> and <i>Scorpaenichthys</i> .
L.Ven.V.	Left ventral vein.
L.V.Fin.A.	Left ventral fin artery.
L.V.Fin.V.	Left ventral fin vein.
Man.	Mandible (Dentary, articular, and angular bones).
Man.A.	Mandibular artery.
Man.V.	Mandibular vein.
Max.	Maxilla.
Max.A. ⁽¹⁾ .	Anterior or maxillary artery.
Max.A. ⁽²⁾ .	Posterior maxillary artery.
Max.V.	Maxillary vein.
Me.A.	Mesencephalic artery.
Mes.A.	Mesenteric artery.
Me.V.	Mesencephalic vein.
M.Lat.A.	Median lateral arteries.
M.Lat.V.	Median lateral veins.
My.	Myelon, myel, or spinal cord.
My.A.	Myelonal artery.
My.V.	Myelonal vein.
N.Br.A.	Nutrient branchial arteries.
N.Br.V.	Nutrient branchial veins.
Neu.A.	Neural arteries.
Neu.L.V.	Neural lymphatic vessels.
Neu.V.	Neural veins.
N.Fil.A. ?	Nutrient branchial filament artery.
N.Fil.V.	Nutrient branchial filament vein.
N.S.	Nasal sac.
N./S. /	Neural spines.
N.S.A.	Nasal sac arteries.
N.S.V. ⁽¹⁾ .	Anterior nasal sac vein.
N.S.V. ⁽²⁾ .	Posterior nasal sac vein.
Obl.	Oblongata or medulla oblongata.
Obl.V.	Oblongata vein.
Oc.Cl.V.	Occipito-clavicularis muscle.
O.D.M.	Obliqui dorsales muscles.
Oes.	Oesophagus.
Olf.L.	Olfactory lobes or bulbs.
O.N.A.	Orbito-nasal artery.
O.N.V.	Orbito-nasal vein.
Op.A.	Opercular artery.
Oph.A.	Ophthalmic artery.
Oph.V.	Ophthalmic vein.

Opt.A.	Optic or retina artery.
Opt.L.	Optic lobes.
Opt.V.	Optic or retina vein.
Op.V.	Opercular vein.
Orb.A.	Orbital artery. In <i>Hydrolagus</i> .
Ov.	Ovaries.
O.V.M.	Obliqui ventrales muscles.
P.A.	Posterior ampulla.
P.A.Bl.A.	Posterior air-bladder artery.
P.A.Bl.V.	Posterior air-bladder vein.
Paras.	Parasphenoid.
P.Aud.A.	Posterior auditory artery.
P.Aud.V.	Posterior auditory vein.
P.C.E.M.	Pharyngo-clavicularis externus muscle.
P.Cer.A.	Posterior cerebral artery.
P.Cer.V.	Posterior cerebral vein.
P.C.I.M.	Pharyngo-clavicularis internus muscle.
P.E.Br.A.	Posterior efferent branchial arteries. In <i>Hydrolagus</i> .
Pec.F.	Pectoral fin.
Pel.	Pelvic arch.
Pel.P.	Ventral process of the pelvic arch.
P.Enc.V.	Posterior encephalic vein.
P.Gas.A.	Posterior gastric artery.
P.Gas.V.	Posterior gastric vein.
P.G.Bl.A.	Posterior gall-bladder artery.
P.G.Bl.V.	Posterior gall-bladder vein.
Phar.A.	Pharynx artery.
Ph.H.M.	Pharyngo-hyoideus muscle.
P.Hyo.A.	Posterior hyoidean artery.
Pig.L.	Pigment layer of the choroid coat.
P.Mes.A.	Posterior mesenteric artery.
P.Mes.V.	Posterior mesenteric vein.
P.P.Ad.M.	Pectoral profundus adductor muscle.
Prec.V.	Precaval vein or Ductus Cuvieri.
Pref.	Prefrontal.
Prem.	Premaxilla.
Preo.	Preopercular.
Pro.	Prootic process.
Ps.A.	Pseudobranchial artery.
P.S.Ad.M.	Pectoral superficialis adductor muscle.
Psen.	Pseudobranchia.
Ps.Fil.Net.	Pseudobranchial filament capillary network.
Py.	Pylorus.
Pyl.A.	Pyloric artery.
Pyl.V.	Pyloric vein.
R.Cæ.A.	Right pyloric cæca artery.
R.Cæ.V.	Right pyloric cæca vein.
R.Car.V.	Right cardinal vein.
R.Cau.A.	Right caudal artery.

R.Cau.V.	Right caudal vein.
Rec.	Rectum.
Rec.A.	Rectus artery.
Rec.V.	Rectus vein.
Ren.A.	Renal arteries.
Ren.P.V.	Renal portal vein.
Ret.	Retina.
Ret.F.	Retina fissure.
R.G.	Gland-like body in retina fissure.
R.Gas.A.	Right gastric artery.
R.Gas.V.	Right gastric vein.
R.Hep.A.	Right hepatic artery.
R.Hep.V.	Right hepatic vein.
R.Hyo.	Ramus hyoideus.
R.Lat.X.	Ramus lateralis vagi.
R.Lat.A.V.	Facialis portion of the ramus lateralis accessorius.
R.Lat.A.X.	Vagus portion of the ramus lateralis accessorius.
R.Man.	Ramus mandibularis VII.
R.Man.V.	Ramus mandibularis trigemini or ramus maxillaris inferior trigemini.
R.Max.V.	Ramus maxillaris trigemini or ramus maxillaris superior trigemini.
R.P.Gas.A.	Right posterior gastric artery.
R.P.Gas.V.	Right posterior gastric vein.
R.Por.V.	Right portal vein.
R.Sper.A.	Right spermatic artery. In <i>Sebastodes</i> .
R.Sper.V.	Right spermatic vein. In <i>Sebastodes</i> and <i>Scorpaenichthys</i> .
R.Ven.V.	Right ventral vein.
R.V.Fin.A.	Right ventral fin artery.
R.V.Fin.V.	Right ventral fin vein.
S.	Suprarenal bodies.
Sac.Vas.	Saccus vasculosus.
Scl.	Sclerotic coat.
Scl.A.	Sclerotic artery.
Scl.Ir.A.	Sclerotic-iris artery.
Scl.V.	Sclerotic vein.
S.D.M.	Superficial dorsal fin muscles.
S.F.	Scapula foramen.
Sil.L.	Silver layer of choroid coat.
Sin.Ven.	Sinus venosus.
S.Lob.V.	Sublobular veins.
Sp.A.	Spinal or myelon arteries.
Sper.A.	Spermatic arteries.
Sper.V.	Spermatic veins.
Spl.	Spleen.
Spl.A.	Splenic artery.
Spl.V.	Splenic vein.
Sp.V.	Spinal or myelon veins.
Sr.A.	Suprarenal artery.

Sr.V.	Suprarenal vein.
St.	Stomach.
Ster.hy.M.	Sternohyoideus muscle.
Ster.A.	Sternohyoideus arteries.
Ster.V.	Sternohyoideus veins.
Sub.A.	Subclavian artery.
Sub.S.	Subclavian sinus.
Sub.V. ⁽¹⁾ .	Internal subclavian vein.
Sub.V. ⁽²⁾ .	External subclavian vein.
Sub.V. ⁽³⁾ .	Minor external subclavian vein. In <i>Ophiodon</i> .
Sup.O.A.	Superior oblique muscle artery.
Sup.O.M.	Superior oblique muscle.
Sup.O.V.	Superior oblique muscle vein.
Sup.R.A.	Superior rectus muscle artery.
Sup.R.M.	Superior rectus muscle.
Sup.R.V.	Superior rectus muscle vein.
Tes.	Testes.
Thym.	Thymus gland.
Thyr.	Thyroid gland.
Thyr.A.	Thyroid artery.
Trap.M.	Trapezius muscle.
Tub.	Tuber (cinereum).
T.V.	Transversus ventralis muscle.
Ur.	Ureters.
Ur.Bl.A.	Urinary bladder artery. (Ur.B.A., in <i>Ophiodon</i> .)
Ur.Bl.	Urinary bladder.
Ur.Bl.V.	Urinary bladder vein. (Ur.B.V., in <i>Ophiodon</i> .)
Ur.S.	Urostyle.
Ut.	Utriculus.
V.Ao.	Ventral aorta.
Vas.L.	Vascular layer of the choroid coat.
V.Chor.V.	Ventral choroid vein.
Ven.	Ventricle.
Ven.A.	Ventral artery.
Ven.A. ⁽¹⁾ .	Posterior ventral artery. In <i>Anoplopoma</i> .
Ven.F.	Ventral or pelvic fins.
Ver.	Vertebra.
V.Gas.A.	Ventral gastric arteries.
V.Gas.V.	Ventral gastric veins.
V.Intc.A.	Ventral intercostal arteries.
V.Intc.V.	Ventral intercostal veins.
V.Lat.A.	Ventral lateral arteries.
V.Lat.V.	Ventral lateral veins.
V.L.V.	Ventral lymphatic vessel.
V.Myo.	Ventral myotomes.
Vo.	Vomer.
V.P.Ad.M.	Ventral or pelvic profundus adductor muscle. " Adductor profundus pelvis of McMurrich.
V.Ret.M.	Venous retia mirabilia of the choroid.

V.S.	Ventral spine.
V.S.Ad.M.	Ventral or pelvic superficialis adductor muscle. Adductor superficialis pelvis of McMurrich.
X.	Place for injecting the arteries.
Y.	Intestinal branch of posterior mesenteric vein.
Z.	Gastric branch of posterior mesenteric vein.
I.	Olfactory nerve.
II.	Optic nerve.
III.	Oculomotor nerve.
IV.	Pathetic or trochlear nerve.
V and VII.	Trigemino-facial complex.
VI.	Abducent nerve.
VIII.	Auditory nerve.
IX.	Glossopharyngeal nerve.
X.	Vagus or pneumogastric nerve.
V ₍₁₎ .	Truncus supra-orbitalis or ramus ophthalmicus superficialis V and ramus ophthalmicus superficialis VII.
V ₍₂₎ .	Truncus infra-orbitalis or buccalis-maxillo-mandibularis.
V ₍₃₎ .	Truncus hyomandibularis or hyoideo-mandibularis facialis.
V.VII.R.	Trigemino-facialis roots.
V.Scl.	Supra-orbital ramus to sclerotic coat.
X.D.	Dorsal root of the vagus.
X.V.	Ventral root of the vagus.