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Original Article

Circulatory system of red tail catfish (*Phractocephalus hemioliopterus* Bloch & Schneider, 1801): a corrosion cast study

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Abstract: Red tail catfish, *Phractocephalus hemioliopterus*, in one of the popular ornamental fish. The present study is aimed to describe and visualizes the cardiovascular system of this species with corrosion cast study method. For this purpose, 10 red tail catfish with 580 gr average weight were obtained and were filled their blood vessels and heart with fluid artificial resin made on the basis of methylmetacrylate after anaesthetizing and euthanizing. For complete polymerization and hardening of the methylmetacrylate, the fish were further submersed for 12-24 hrs in water bath following by 24-48 hrs submersion in a 25% solution of KOH to full maceration. Based on the results we describe the cardiovascular system i.e. the afferent and efferent vessels of gill, different parts of the heart, ventral aorta, dorsal aorta, intestinal and gastric vessels, liver, anterior and posterior parts of the kidneys, spleen, portal and hepatic vein.

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Introduction

The circulatory system plays an important role in many modeling approaches, therefore understanding its anatomy can be useful for many basic and diagnostic studies (Nematollahi et al., 2003, 2005; Noestelthaller et al., 2005; Ghadam et al., 2016). Vascular corrosion casting consists of injecting a liquid polymer into the circulatory system of a whole animal or an organ, allowing it to harden and then corroding away the overlying tissue (typically with potassium hydroxide solution) to produce a 3D cast of the internal structure of the vessels (Hossler et al., 1986, 1991; Zeindler et al., 1989). It will be possible to study the vascular structures in 3D by corrosion cast studies. This would give more information about the complexity of the vascular system in various species (Schmidt et al., 1980). This method has been used in many studies on human and animals.

Few studies have been performed on the cardiovascular system of fishes (Seyed Ali et al., 1987; Passantino et al., 2000; Basten et al., 2009) such as light and scanning electron microscopic observations on methyl-methacrylate corrosion casts of the blood vessels in the gills of channel catfish (*Ictalurus punctatus*) (Boland and Olson, 1979), corrosion cast of the entire blood vascular system by a single injection of resin from the heart of a Japanese catfish (*Silurus asotus*) (Iwamizu and Itazawa, 1986), gill vasculature of yellow stingray (*Urolophus jamaicensis*) using resin casts under SEM (Sherman and Spieler, 1998), spatial organization of the microcirculation in gills of striped mullet (*Mugil cephalus*) by scanning electron microscopic analysis of corrosion cast prepared by intravascular injection of methylmethacrylate (Passantino et al., 2000), structural variation in gill vasculature among some elasmobranchs using corrosion casting and SEM (Sherman et al., 2005), vascular pattern of the recirculating system of rainbow trout (*Oncorhynchus mykiss*) by corrosion cast methodology (Nematollahi et al., 2011), the efferent branchial arteries and splanchnic arteries in the yellow stingray (*Urobatis jamaicensis*) using SEM to study the vascular corrosion casts (Basten et al., 2009), and comparative study of the circulatory system in common carp (*Cyprinus carpio*) and beluga (*Huso huso*) with

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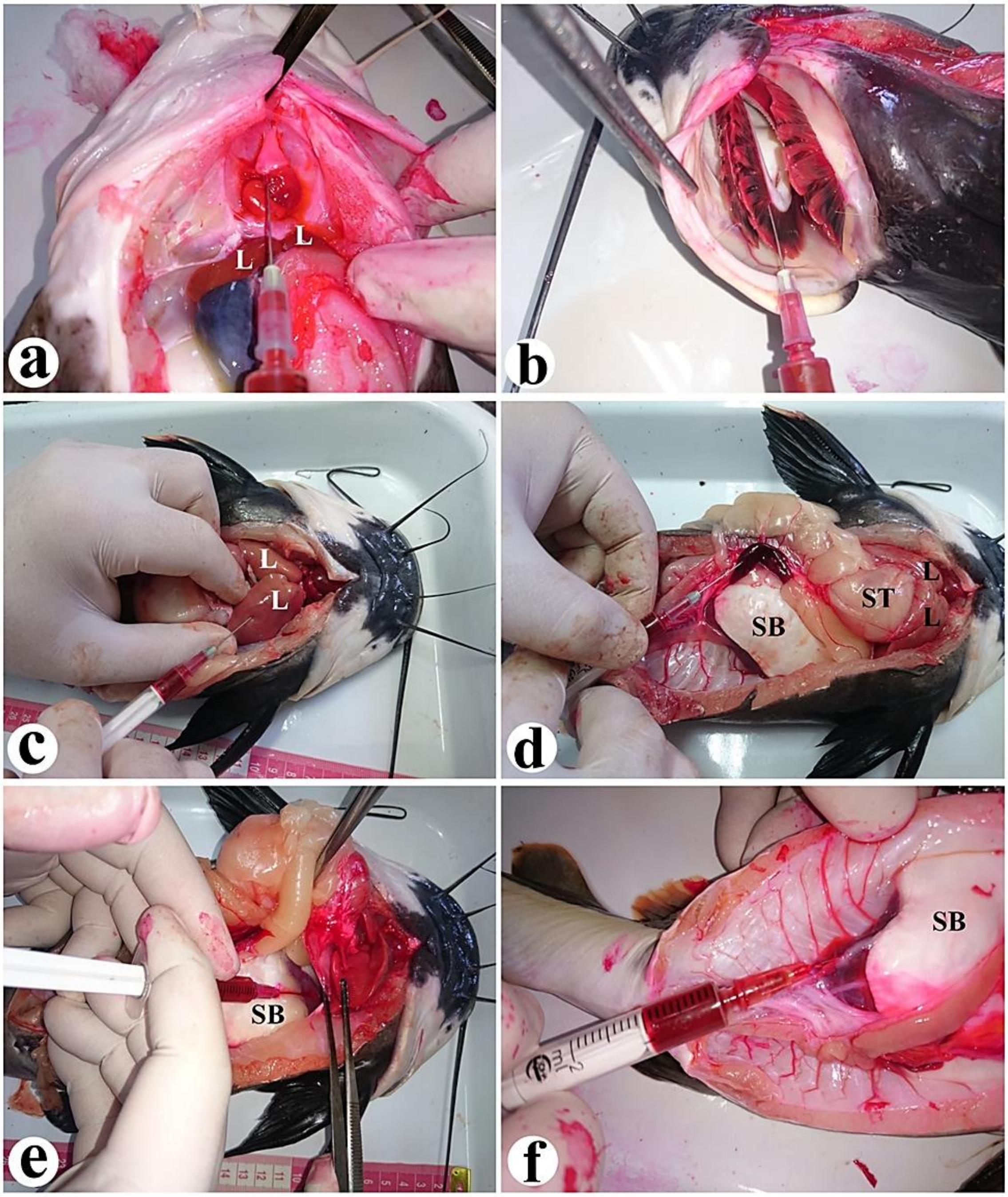

Figure 1. Injection of artificial resin fluid into the heart (a), branchial vessels (b), liver (c), spleen (d), anterior kidney (e) and posterior kidney (f). (L) Liver, (SB) Swim bladder, (ST) Stomach.

emphasis on the heart and main blood vessels, employing the corrosion cast methodology (Ghadam et al., 2016).

Red tail catfish, *Phractocephalus hemioliopterus* is a large Neotropical catfishes of the family Pimelodidae, inhabiting the Amazon and Araguaia-Tocantins River basins. This fish is characterized by having a strong skull ossification, a huge and bony predorsal plate, and red-orange tail and dorsal fins (Goulding, 1980). It has a great economic importance as an ornamental fish, sport fishing or fish production, providing food and a valuable source of income for coastal populations, and also in some regions of the Amazon, its fat and leather extracted are used as folk medicine for treating respiratory problems (Souza et al., 2012). The present study describes and visualizes a 3D view of the circulation system of this fish using the corrosion cast methodology as an important

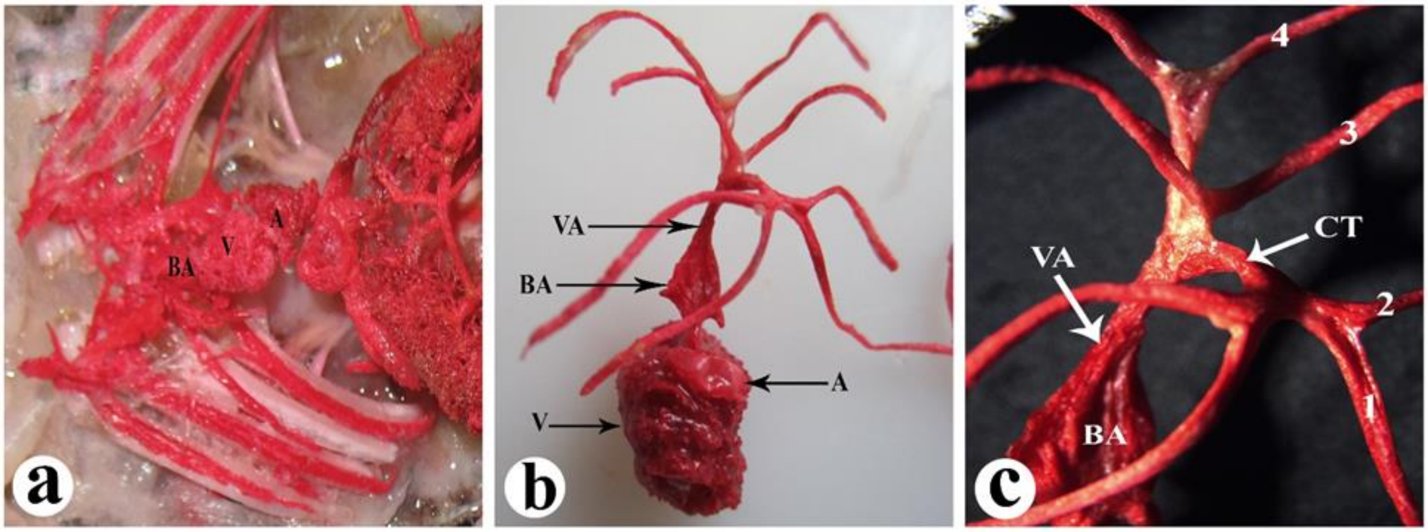

Figure 2. A, B and C: the main parts of the heart and related vessels. A (Atrium), BA (Bulbus arteriosus), CT (Common trunk), V (Ventricle), VA (Ventral aorta) and ABAs (1-4). Each ABAs itself constituted afferent filament arteries (AFAs) (secondary lamella), that provide more surface for oxygen exchange (Fig. 3a and b).

ornamental fish.

Materials and Methods

Ten red tail catfish with average weight of 580 g were obtained from ornamental fish supply stores in Tehran, Iran. Fish were kept for 2 weeks prior to the experiment in 1000-L tanks supplied with filtered, recirculated tap water (23±1°C). Dissolved oxygen and pH were 6.5±0.5 mg/L and 7±0.3, respectively. Wet smears from skin, fins and gills was prepared for parasitological examination under light microscope (Nikon, E600). No ectoparasite were observed. The fish were anesthetized using PI222 (Pars Imen Daru, Iran) in dosage of 100 ppm and transferred to the operating table. To prevent the formation of blood clots in the vessels, the fish were injected intraperitoneally with heparin (5000 Iu/kg) and euthanized with an overdose of the aforementioned anesthetic solution. Then the heart and blood vessels were filled with artificial resin fluid made on the basis of methylmetacrylate. This solution was injected in the heart, branchial vessels, liver, spleen, anterior, and posterior part of the kidney (Fig. 1a-f). Fish were left for 12-24 hrs in a 20-24°C tap water bath to complete polymerization of the injected resin. Then dipped in 25% potassium hydroxide (KOH) for 24-48 hrs to maceration of the tissues (Ghadam et al., 2016). The resin did not dissolve in potassium hydroxide, thus the heart and vascular casts remained in their natural positions. These structures were studied by gross examination and stereomicroscope.

Results

The results are illustrated in Figures 1-12 to provide information on the cardiovascular system. Different parts of the heart and related vessels, including Atrium (A), Ventricle (V), Bulbus arteriosus (BA) and Ventral aorta (VA) were shown in Figure 2a, b. The VA continues from the heart to the afferent branchial arteries (ABAs) (Fig. 2c). The length of VA is short. In a short distance from the heart, a common trunk (CT) is separated from VA. The common trunk is divided into two branches (ABA 1 and 2) and the rest of VA separately made ABA 3 and 4 (Fig. 2c).

The DA continues along the vertebral column and supplied different parts of the body. In a short distance from the beginning of DA, a branch viz. Subclavian artery (SCA) was separated to supply the cranial parts of body such as pectoral fins (Fig. 5). In the middle of the body, it passed through a Longitudinal groove (LG) in WB (Fig. 6a). It supplies this part of the body through some pores (P) in the bones (Fig. 6a, b, c). In caudal area, the DA passed through haemal arches (HA). DA and Caudal vein (CV) which carried the

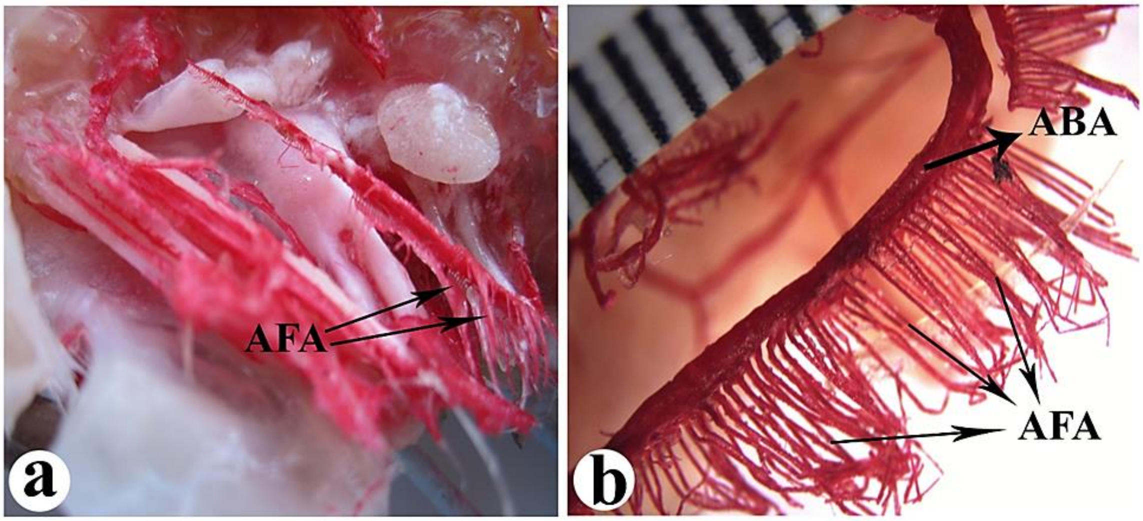

Figure 3. ABA (Afferent branchial arteries) and AFA (Afferent filament arteries) are seen. After oxygen exchange, ABAs joined together and made Efferent branchial arteries (EBAs). EBAs joined together and formed dorsal aorta (DA) at the beginning of Weber bone (WB) (Fig. 4). Some branches such as Orbital artery (OA) and Encephalic artery (EA) separated from EBAs and supplied blood to different anterior parts of the body. (Fig. 4).

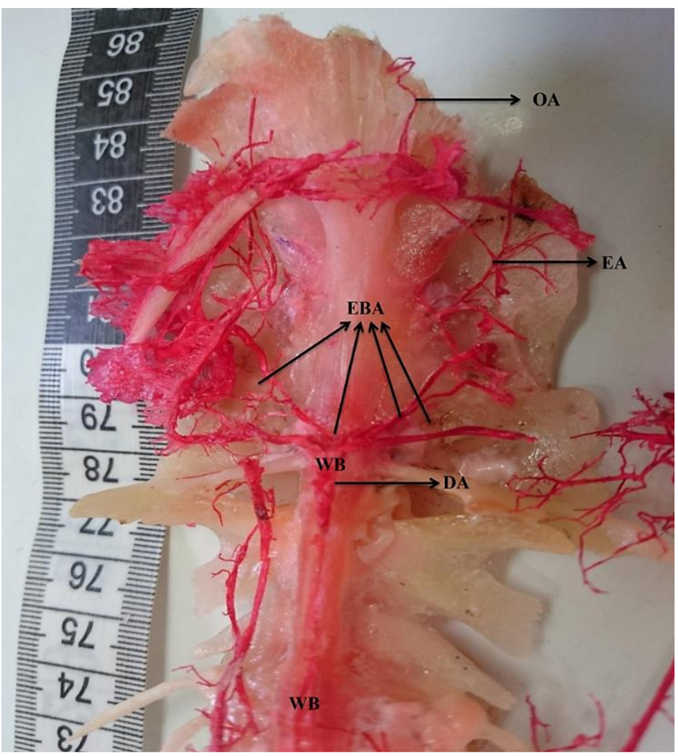

Figure 4. Formation of dorsal aorta by joining of EBAs. DA (Dorsal aorta), EBA (Efferent branchial arteries), EA (Encephalic artery) and WB (Weber bone). ABAs and AFAs were removed.

deoxygenate blood, are passed together in HA (Fig. 7).

The venous blood from the caudal area such as caudal fin, ribs, trunk muscles and bones is collected by CV. Many small vessels collect the venous blood, forming CV that goes to the anterior parts of the body. CV in its path is unified with the venous vessels from the spleen, stomach, intestine, gall bladder, and mesenteric vein and then carries as Portal vein (PV) to the liver (Fig. 8). The collected blood in the liver is entered to the heart via Hepatic vein (HV) (Fig. 8). The blood from the posterior kidneys is collected by the Renal portal vein (RPV) and then is carried by the right post cardinal vein (RPCV) and left post cardinal vein (LPCV) to the Common cardinal vein (CCV) and then to the heart. RPCV and LPCV are passed inside the bone plates on both right and left sides of the body. In total, RPCV is thicker than LPCV (Fig. 8).On the

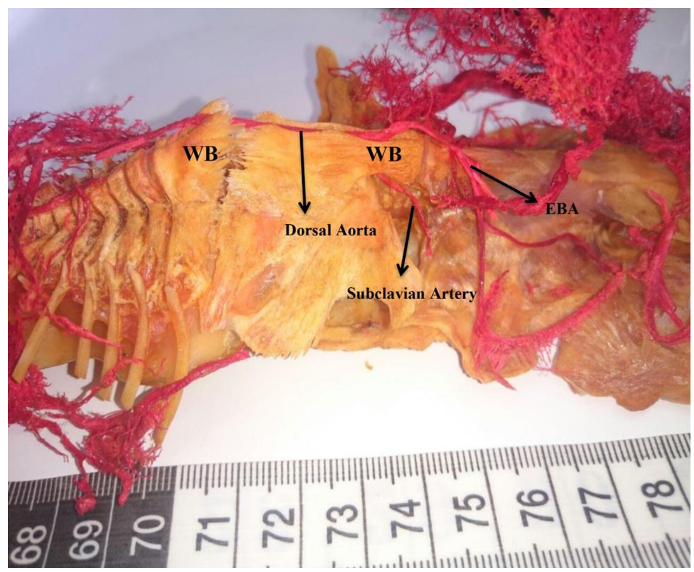

Figure 5. DA (Dorsal aorta), EBAs (Efferent branchial arteries), SCA (Subclavian artery) and WB (weber bone) are seen.

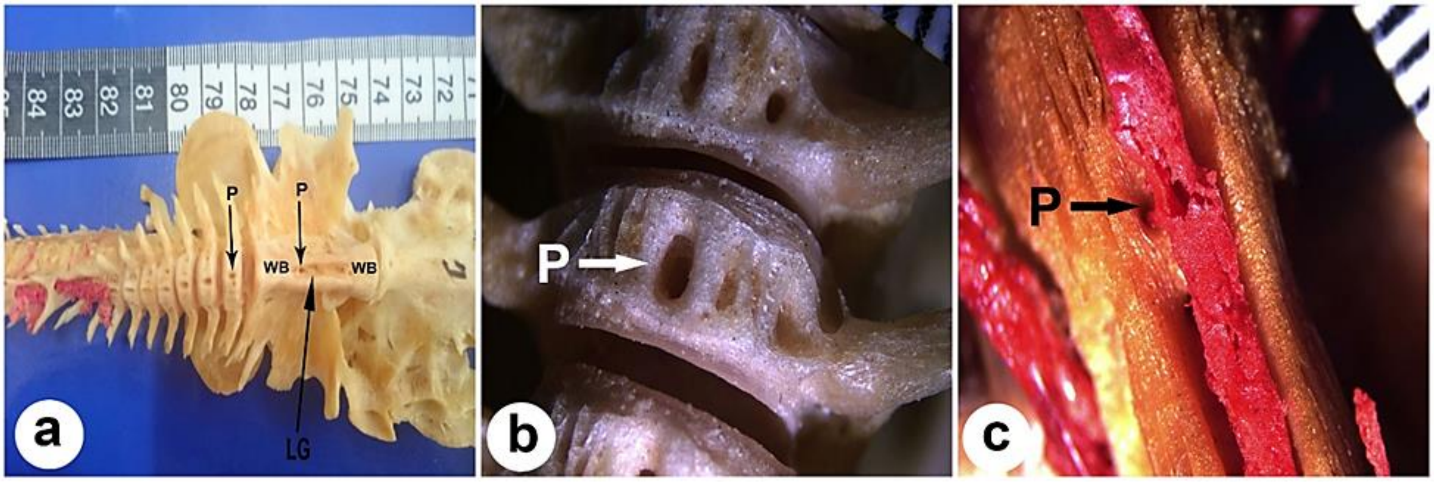

Figure 6. LG (longitudinal groove) and WB (Weber bone) and P (pores of the weber bone and other vertebrae).

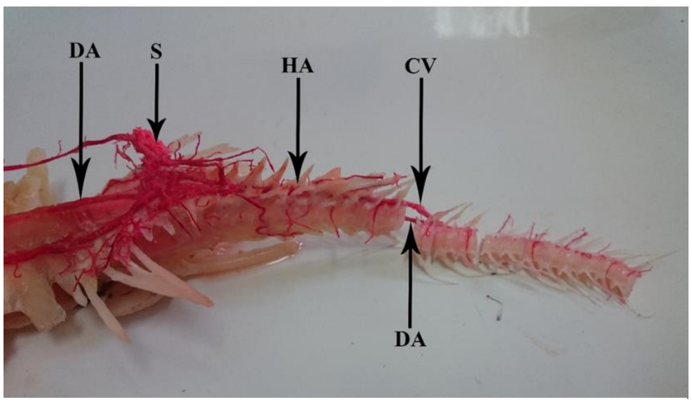

Figure 7. Vessels passing through the haemal arches. CV (Caudal vein), DA (Dorsal aorta), HA (Haemal arch) and S (Spleen).

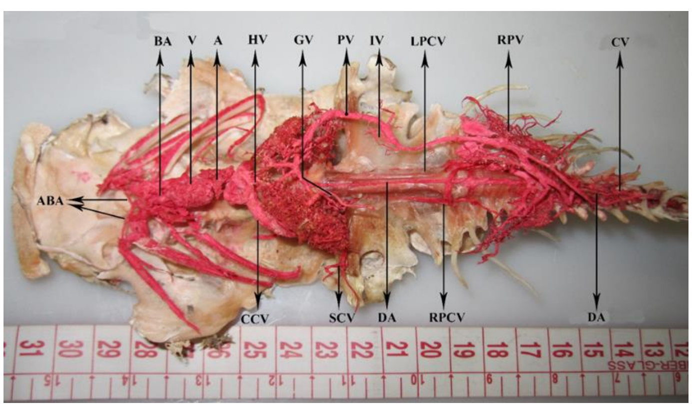

Figure 8. The path of the blood vessels from caudal area to the heart. A (Atrium), ABAs (Afferent branchial arteries), BA (Bulbus arteriosus), CCV (Common cardinal vein), CV (Caudal vein), DA (Dorsal aorta), GV (Gastric vein), HV (Hepatic vein), IV (Intestinal vein), LPCV (Left post cardinal vein), PV (Portal vein), RPCV (Right post cardinal vein), RPV (Renal portal vein), SCV (Subclavian vein) and V (Ventricle).

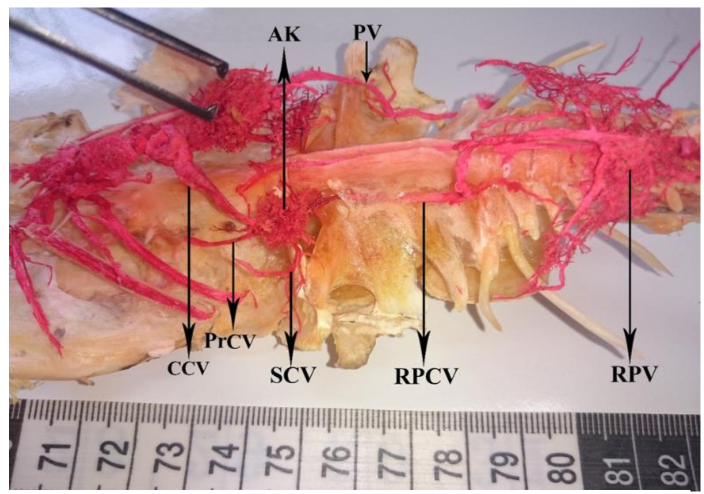

Figure 9. AK (Anterior kidney), CCV (Common cardinal vein, PV (portal vein), PrCV (Precardinal vein), RPCV (Right post cardinal vein), RPV (Renal portal vein) and SCV (Subclavian vein).

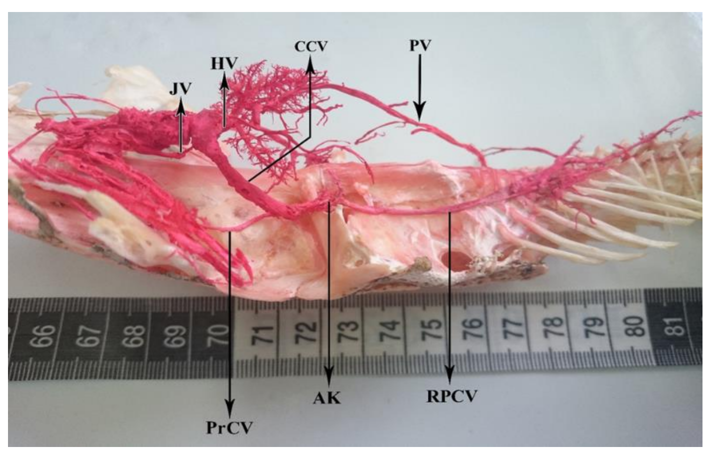

Figure 10. AK: Anterior kidney, CCV: Common cardinal vein, HV: Hepatic vein, JV: Jugular vein, PrCV: Precardinal vein, RPCV: Right post cardinal vein and PV: portal vein.

other hand, the blood from anterior part of the kidneys (AK) and subclavian vein (SCV) are joined to the RPCV and LPCV entering CCV (Fig. 9). The pecardinal vein (PrCV) transports the major parts of the blood from the head and brain to the heart through

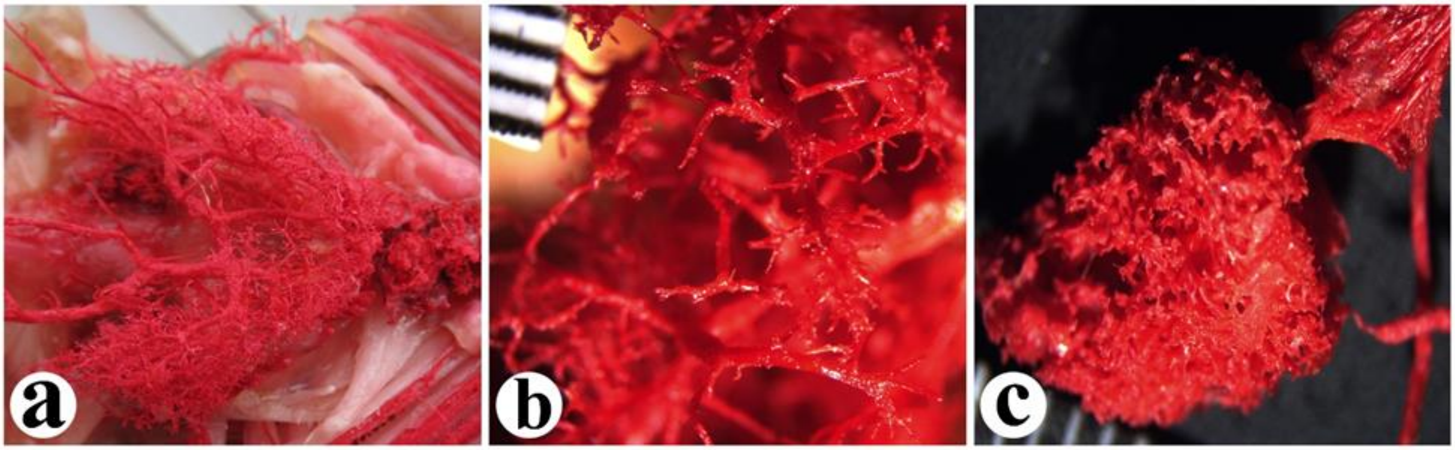

Figure 11. Vessels plexus in the heart and the liver. (a and b): liver and (c) heart.

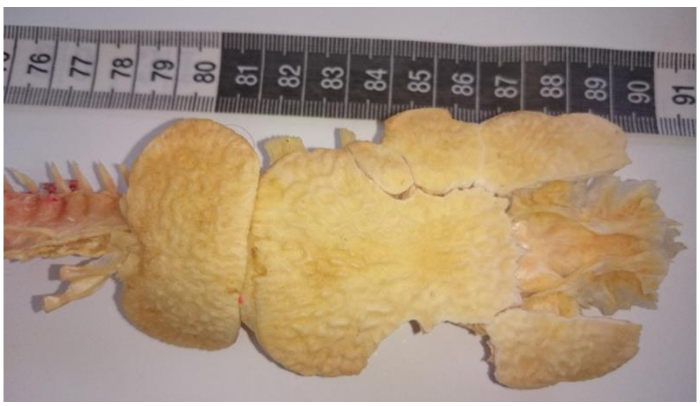

Figure 12. Dorsal view of the predorsal plate of red tail catfish.

CCV. The right PrCV and RPCV are joined as a common part constituting CCV (Figs. 9, 10). Jugular vein (JV) transports the rest part of the blood from the head to CCV separately (Fig. 10). Finally, the collected blood in CCV is transported to the heart on right and left sides. The casts from liver showed wide vessels plexus (Fig. 11a, b, c). Bone plates had a dorso-ventral appearance extending from the head to the anterior part of the tail (Fig. 12).

Discussion

The corrosion cast study method can be used in pathological malformations and comparative anatomy (Zeindler et al., 1989; Hossler and Douglas, 2001; Nematollahi et al., 2011). In present study, the circulatory system of *P. hemioliopterus* including the different parts of heart and its vessels such as branchial arteries, dorsal aorta, common cardinal vein and hepatic vein were studied by corrosion cast methodology. We obtained a full casts of blood vessels perfusing various organs such as liver, stomach, spleen, posterior kidney and anterior kidney. According to observations, the length of the ventral aorta was short and after a short distance from the heart, a common trunk is separated from the ventral aorta. This branch is divided into two branches forming the branchial artery 1 and 2. In the following, the branchial artery 3 and 4 divided separately. These observations is correspond with those vascular pattern of common carp, but different with those of beluga and yellow stingray, showing similar pattern in bony fishes. However, there are some structural differences with common carp.

The results also showed that the liver has two lobes of the same size locating behind of the heart. The caudal vein joins to the portal vein at the left side. As regards one of the most important problem in this fish is swallowing foreign bodies and subsequently it needs to surgical or non-surgical procedures (Chansue and Tangtrongpiros, 2005; Ebrahimzadeh et al., 2006; Wildgoose, 1998), therefore the results suggests that during surgical procedures it would be better that the incision must be done at right side of midline of this catfish.

In most studies, the remained casts from liver show a wide vessel plexus because of high metabolic activity of this organ. According to the result, the right post cardinal vein (RPCV) was thicker than left post cardinal vein (LPCV) in *P. hemioliopterus* showing that major part of the blood of the renal portal vein is carried by (RPCV) that has not been reported in previous studies. However, presentation of a complete blood vessel system using a single corrosion cast can be led artifacts due to the extremely fine capillaries. Furthermore researches are suggested to be done on other catfishes for comparison purpose.

Acknowledgments

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چکیده فارسی

سیستم گردش خون گربه ماهی ردتیل (*Phractocephalus hemioliopterus* **Bloch & Schneider, 1801**): مطالعه قالب‌گیری تحلیلی عروق

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چکیده:

گربه ماهی ردتیل (*Phractocephalus hemioliopterus*) یکی از ماهیان زینتی معروف است. هدف از این تحقیق مشاهده و توصیف سیستم گردش خون این گونه با استفاده از روش قالب‌گیری تحلیلی عروق می‌باشد. برای این منظور از ۱۰ عدد ماهی ردتیل با متوسط وزن ۵۸۰ گرم استفاده شد. پس از بیهوشی، قلب و عروق خونی ماهیان با رزین مصنوعی ساخته شده از متیل‌متاکریلات پر شد. برای تکمیل پلیمریزه و سخت شدن متیل متاکریلات، ماهیان در ادامه به‌مدت ۲۴-۱۲ ساعت در حمام آب و سپس به مدت ۲۴-۴۸ ساعت در محلول ۲۵٪ KOH غوطه ور شدند. در نهایت سیستم گردش خون به شکل عروق آوران و وابران آبشش، بخش های مختلف قلب، آئورت شکمی، آئورت پشتی، عروق روده، معده و کبد، عروق خلفی و قدامی کلیه، طحال و نیز سیاهرگ پورتال و کبدی مشخص و نشان داده شد.

کلمات کلیدی: سیستم گردش خون، گربه ماهی ردتیل، قالب‌گیری تحلیلی عروق، فیزیولوژی.