ORIGINAL RESEARCH PAPER

Animal Science

SACCUS VASCULOSUS AS A PHOTONEUROENDOCRINE ORGAN IN FISH

KEY WORDS: Saccus Vasculosus, Neuroendocrine System, Seasonal Reproduction

S. Selvaraj*	Dr. M.G.R. Fisheries College & Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Ponneri, Thiruvallur, Tamil Nadu. *Corresponding Author
N. Jayakumar	Dr. M.G.R. Fisheries College & Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Ponneri, Thiruvallur, Tamil Nadu.
P. Pavinkumar	Dr. M.G.R. Fisheries College & Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Ponneri, Thiruvallur, Tamil Nadu.
C.B.T. Rajagopalsamy	Dr. M.G.R. Fisheries College & Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Ponneri, Thiruvallur, Tamil Nadu.
B. Ahilan	Dr. M.G.R. Fisheries College & Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Ponneri, Thiruvallur, Tamil Nadu.
S. Felix	Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Vettar River View Campus, Nagapattinam,, Tamil Nadu.

INTRODUCTION

Circumventricular organs are brain structures lining the cavity of the third and fourth ventricles. The saccus vasculosus is a circumventricular organ unique to many jawed fish, which is located posterior to the pituitary gland and between the inferior lobes of the hypothalamus. It is considered as saccular protrusion of the caudal infundibular wall of the diencephalon and located in the vicinity to the hypophyseal complex. The cavity of this organ is continuous with the third ventricle of the brain (Hofer, 1958; Watanabe, 1966; Khanna and Singh, 1967). However, some fish appear to lack this organ completely and it is not found in the jawless fish (Lanzing, 1970).

The degree of development of the saccus vasculosus varies among species. Saccus vasculosus of the shark is a paired organ, while that of teleosts is an unpaired organ (Sato and Kurotaki, 1958). According to Boeke and Dammerman the saccus is large in sea-fish, smaller in river-fish, and almost lacking in fishes of canals and ponds (Dammerman, 1910). Saccus vasculosus occurs in most marine fish, although there are exceptions such as pomacentridae, scomberesocidae, and coryphaenidae. In freshwater fish, saccus vasculosus is absent in cyprinidae, esocidae, and poecilidae (Mecklenburg, 1974).

The saccus vasculosus has been suggested to be involved in sensory, secretory, and transport functions. The different functions include hydrostatic pressure perception, osmoregulation, calcium homeostasis, glucose loading and transcellular ion exchange between the blood vessels and cerebrospinal fluid (Sueiro et al., 2007). Recent studies indicate that saccus vasculosus serves as a sensor responding to photoperiodicity and expresses all the components in the regulation of the seasonal reproduction in fish (Nakane et al., 2013; Tian et al., 2019).

Morphology and histology of saccus vasculosus

Morphology and histology of saccus vasculosus varies among fish species. Three groups have been demonstrated in teleosts based on the morphology of infundibular region. The first is formed by species which have a broad infundibulum and a small recessus hypophyseos but completely lack a saccus vasculosus. In the second group, a broad infundibulum with a rostral recessus hypophyseos and a more or less large saccus vasculosus. In the third group, a broad infundibular region with a rostral recessus hypophyseos and a caudal saccus evagination of large size (Gentes, 1907; Dammerman, 1910; Stendell, 1914; Bock, 1928). Based on the size of saccus vasculosus, Tsuneki (1986, 1992) have defined different types in teleosts. The complete absence of the saccus vasculosus is marked as type 0. Type 0 also represents a tiny diverticulum or a cell sheet attached to the ventrocaudal wall of the hypothalamus. Type 1 represents a caudally elongated tube-or disclike saccus vasculosus and the epithelial wall is not folded and is not covered with sinus-like blood vessels. Type 2 represents a moderately or poorly developed saccus vasculosus usually smaller than the pituitary. The epithelial wall is moderately folded or not folded. The vascularization is not extensive or rather poor. Type 3 represents a well-developed saccus vasculosus usually larger or only slightly smaller than the pituitary gland. The epithelial wall is highly folded and is densely covered with sinus-like blood vessels.

Saccus vasculosus has been investigated in a number of Indian teleosts (Sundararaj and Prasad, 1964; Rao, 1966; Khanna and Singh, 1967; Joy and Satyanesan, 1979; Ghosh and Chakrabarti, 2010; Khatun and Chakrabarti, 2016; Chakrabarti and Katun, 2017). The epithelium of the saccus vasculosus is monolayered and composed of coronet cells, glial cells and cerebrospinal fluid-contacting neurons. Each cell types are characterized by morphological differences in teleosts. Generally, the coronet cells (also known as sense or crown cells) are cubic to rectangular in sections and larger in size; while, the supporting glial cells are interspersed between them. Each coronet cell has an elongated body consisting of a basal and an apical part. The large spherical nucleus is situated in the basal part of the cell. The apical portion of the cell projects into the cavity of the saccus and bears a varying number of ciliary processes or 'hairs', each possessing a globular extension at its tip. The supporting cells are smaller and the nucleus lies in the middle of the cell body. Glia cells usually surround the body of each coronet cell, separating it from the basal membrane. Glial cells are devoid of apical protrusions and hairs. Cerebrospinal fluid-contacting neurons are the cells resembling coronet cells with no globules on their head, with only one or two cilia are. The nucleus is roundish and occupies most of the cell body. CSF-contacting neurons are bipolar neurons with a knob-like structure; their morphology resembles that of photoreceptor cells in the developing retina (Dammerman, 1910; Khanna and Singh, 1967; Gupta, 2007, 2009). The Osteoglossiformes are all freshwater teleosts and the saccus vasculosus is virtually absent in this group except for the Notopteridae (Notopterus chitala, Papyrocranus afer and Xenomystus nigri) (Rossi and Monaco, 1977; Ghosh and Chakrabarti, 2010; Chakrabarti and Katun, 2017).

In shark Scylliorhinus caniculus the saccus vasculosus develops as an infundibular evagination. The ventral wall of the evagination develops into neurohypophyseal tissue, and the dorsal into saccus vasculosus epithelium (Van de Kamer and Schuurmans, 1953). The coronet cells have a mulberry like structure in sharks. In ray (Dasrratis akajei), saccus vasculosus consists of follicles whose walls are lined with the epithelium made up of two cell types: the coronet cells and the supporting cells. Additionally, a special type of epithelial cell, flask-like in shape and filled with many mitochondria are scattered in the saccus vasculosus (Watanabe, 1966; Rodriguez-Moldes and Anadon, 1988; Sueiro et al., 2007).

Role of saccus vasculosus

The coronet cells and cerebrospinal fluid contacting neurons have been shown to be primarily responsible for the function of the saccus vasculosus. Coronet cells regulate the composition of the cerebrospinal fluid by sodium-dependent resorption of low molecular weight metabolites from the ventricular system (Jansen, 1975, 1978). A resorptive function of the coronet cells in the homeostasis of the cerebrospinal fluid in rainbow trout have been demonstrated (Jansen and Dort, 1978). Immunocytochemical studies of the saccus vasculosus in teleosts have demonstrated acetylcholinesterase activity and cerebrospinal fluid contacting neurons immunoreactive to gamma-aminobutyric acid acid, glutamic acid decarboxylase, parathyroid hormone-related protein, and neuropeptide Y (Vigh-Teichmann et al., 1970; Zimmermann and Altner, 1970; Jansen and West, 1971; Vigh et al., 1972; Jansen, 1975, 1978; Chiba et al., 1996a, b; Devlin et al., 1996; Yáńez et al., 1997; Sueiro et al., 2007). Similarly, several neuropeptides immunoreactive to the above peptides in the teleosts were demonstrated in the elasmobranch brain. Also, the existence of saccopetal monoaminergic and neurosecretory fibers showed reciprocal connections between the saccus vasculosus and hypothalamic structures in elasmobranchs (Sueiro et al., 2007). The importance of calcium buffering in the function of coronet cells of developing turbot (Scophthalmus maximus) have been demonstrated (Cid et al., 2015).

Seasonal fish reproduction is controlled by multiple photoneuroendocrine centers such as eye, pineal gland, hypothalamus and saccus vasculosus. Among environmental cues, photoperiod is considered as an important determinant of reproduction via neuroendocrine regulation. Based on the relative day-length during the reproductive season, fish are classified into long-day and short-day breeders (Nishiwaki-Ohkawa and Yoshimura, 2016). For long-day breeders like medaka and Atlantic salmon, increased day length induces brain GnRH production, which facilitates FSH and LH synthesis as well as gonad development (Yoshimura, 2013; Shinomiya et al., 2014). Recent studies indicate that the long photoperiod can promote the expression of kisspeptin and their receptors in the brain, including saccus vasculosus (Chi et al., 2017), suggesting the involvement of kisspeptin systems in modulation of reproductive axis in fish. In Atlantic salmon (Salmo salar) both kissr and hypophsiotrophic GnRH form are also expressed in the saccus vasculosus (Zohar et al., 2010; Chi et al., 2017). It is likely that photoperiod changes act at different levels, including saccus vasculosus to modulate seasonal reproduction in fish. Recent studies indicate that the morphological differentiation of saccus vasculosus occurs during the embryonic stage but that the functional differentiation into a seasonal sensor occurs in a later developmental stage (Maeda et al., 2015). Therefore, there is necessary to sample saccus vasculosus at different life cycle stages to confirm the morphological and functional differentiation periods in the experimental fish to analyze reproductive function

Future perspectives

Lanzing (1970) demonstrated the presence of saccus vasculosus in American and Indian cichlids, and a distinct saccus vasculosus was found in Etroplus maculatus. Recently our group succeeded in natural and induced breeding of pearl spot in FRP tanks (Felix et al., 2017). Using similar experimental set up, Ruby et al. (2018) evaluated photoperiod combinations of 1000 lux/6 hours, 1000 lux/8 hours, 1000 lux/10 hours and control on seed production of pearlspot for 90 days. The results indicated that 6L:18D treatment produces significantly greater number of seeds in single spawning than the treatment with longer photoperiods and control. There is possibility that saccus vasculosus, including other light sensitive organs are involved in photoperiod transduction in the pearlspot (Etroplus suratensis), as this species mostly spawn during day time in the tank (personal observation).

REFERENCES

1. Bhatnagar, A.N., Al-Noori, S.A., Gorgees, N.S., 1978. Studies on the histomorphology and histochemistry of the saccus vasculosus of Cyprinion macrostomus. Acta anatomica 100: 221-228.
2. Bock, Fr., 1928. Die Hypophyse des Stichlings (Gasterosteus aculeatus L.) unter besonderer Berücksichtigung der jahrescyklischen Veränderungen. Z. wiss. Zool. 131: 645-710.
3. Chakrabarti, P., Khatun, R., 2017. Histophysiological and surface ultrastructural studies of the saccus vasculosus of Notopterus chitala (Hamilton). J. Micro. Ultra. 5: 140–145
4. Chi, L., Li, X., Liu, Q., Liu, Y., 2017. Photoperiod regulate gonad development via kisspeptin/kissr in hypothalamus and saccus vasculosus of Atlantic salmon (Salmo salar). PlosOne 12: e0169569.
5. Chiba, A., Sohn, Y.C., Honma, Y., 1996a. Distribution of neuropeptide Y and gonadotropin-releasing hormone immunoreactivities in the brain and hypophysis of the Ayu, Plecoglossus altivelis (Teleostei). Arch. Histol. Cytol. 59: 137-148.
6. Chiba, A., Sohn, Y.C., Oka, S., Honma, Y., 1996b. Localization of neuropeptide Y-like immunoreactivity in the saccus vasculosus of cartilaginous and bony fishes. Zool. Sci. 13: 347-350.
7. Cid, P., Doldán, M.J., de Miguel Villegas, E., 2015. Morphogenesis of the saccus vasculosus of turbot Scophthalmus maximus: assessment of cell proliferation and distribution of parvalbumin and calretinin during ontogeny. J. Fish Biol. 87: 17-27
8. Dammerman, K.W., 1910. Der Saccus vasculosus der Fische ein Tiefeorgan. Z. wiss. Zool., xcvi: 654-726.
9. Devlin, A.J., Danks, J.A., Faulkner, M.K., Power, D.M., Canario, A.V.M., Martin, T.J., Ingleton, P.M., 1996. Immunochemical detection of parathyroid hormone-related protein in the saccus vasculosus of a teleost fish. Gen. Comp. Endocrinol. 101: 83-90.
10. Felix S. First report on induced spawning of Indian pearl spot (Etroplus suratensis). J. Entomol. Zool. Studies. 2017; 5:709-713.
11. Gentes, l., 1907. Recherches sur l'hypophyse et le sac vasculaire des vertébrés. Trav. Lab., Soc. Sei. Arcachon, 10: 129-281.
12. Ghosh, S.K., Chakrabarti, P., 2010. Histological studies of saccus vasculosus of fishes Notopterus notopterus (Pallas) and Ompok bimaculatus (Bloch) Env. Ecol. 28: 34-37
13. Gupta, A., 2007. Studies of saccus vasculosus of Anabas testudineus and Colisa fasciatus with reference to secertory functions. J. App. Zool. Res. 18: 64-66.
14. Gupta, A., 2009. Morphological variation in shape and size of saccus vasculosus of Anabas testudinelis. Uttar Pradesh J. Zool. 29: 229-232.
15. Hofer, H., 1958. Zur morphologie der circumventriculären Organe des Zwischenhirnes der Säugetiere. Verh. Dtsch. Zool. Ges. 202-251.
16. Jansen, W.F., 1975. The saccus vasculosus of the rainbow trout, Salmo gairdnerii Richardson. A cytochemical and enzyme-cytochemical study, particularly with respect to coronet cells and glial cells. Neth. J. Zool. 25: 309-331.
17. Jansen, W.F., van Dort, J.B., 1978. Further investigations on the structure and function of the saccus vasculosus of the rainbow trout, Salmo gairdneri Richardson. Cell Tiss. Res. 187: 61-68.
18. Joy, K.P., Sathyanesan, A.G., 1979. A histoenzymological study of the saccus vasculosus of the fresh water teleost, Clarias batrachus (L.). Z. Mikrosk. Anat. Forsch. 93: 297-304.
19. Khanna, S.S., Singh, H. R., 1967. Histology and histochemistry of the saccus vasculosus in some teleosts (Pisces). Acta anat. 67: 304-311.
20. Khatun, R., Chakrabarti, P., 2016. Histological and surface ultrastructural observations on the saccus vasculosus of Eutroiichthys vacha (Hamilton). Int. J. Fish. Aquat. Studies 4(6): 112-117.
21. Lanzing, W.J., 1970. The development of a saccus vasculosus in Tilapia mossambica Peters and other cichlids. J. Fish Biol. 2: 249-252.
22. Maeda, R., Shimo, T., Nakane, Y., Nakao, N., Yoshimura, T., 2015. Ontogeny of the saccus vasculosus, a seasonal sensor in fish. Endocrinology 156: 4238-4243.
23. Mecklenburg, von C., 1974. The development of saccus vasculosus in two teleosts. Acta Zoologica 55: 137-148.
24. Nakane, Y., Ikegami, K., Iigo, M., Ono, H., Takeda, K., Takahashi, D., et al., 2013. The saccus vasculosus of fish is a sensor of seasonal changes in day length. Nat. Commun. 4: 2108.
25. Nishiwaki-Ohkawa T, Yoshimura T, 2016. Molecular basis for regulating seasonal reproduction in vertebrates. J. Endocrinol. 229: 117-127.
26. Rao, P.D., 1966. On the saccus vasculosus in some Indian freshwater teleosts. Naturwissenschafte 53:233.
27. Rodriguez-Moldes, M.I., Anadon, R., 1988. Ultrastructural study of the evolution of globules in coronet cells of the saccus vasculosus of an elasmobranch (Scyliorhinus canicula L.) with some observations on cerebrospinal fluid-contacting neurons. Acta Zool. 69: 217-224.
28. Rossi, A., Monaco, G., 1977. Ultrastructure of the saccus vasculosus of Notopterus chitala (Pisces Osteoglossiformes). Boll. Zool. 44: 295-309.
29. Ruby, P., Ahilan, B., Felix, S., Samuel Mosses, T.L.S., 2018. Effect of photoperiod on pearl spot (Etroplus suratensis) seed production under hatchery conditions. J. Entomol. Zool. Studies 6: 1120-1124.
30. Sato, M., Kurotaki, M., 1958. Notes on the saccus vasculosus of some Japanese fishes. Japan. J. Ichthol. 7: 39-44.
31. Shinomiya, A., Shimmura,T., Nishiwaki-Ohkawa, T., Yoshimura, T., 2014. Regulation of seasonal reproduction by hypothalamic activation of thyroid hormone. Front. Endocrinol. 5:12.
32. Stendell, W., 1914. Die Hypophysis cerebri der Vertebraten. In Oppel, A., Lehrbuch der vergl. mikrosk. Anat. 8. Jena: Gustav Fischer.
33. Sueiro, C., Carrera, I., Ferreiro, S., Molist, P., Andrio, F., Anadon, R., Rodriguez-Moldes, I., 2007. New insights on saccus vasculosus evolution: a developmental and immunohistochemical study in elasmobranchs. Brain Behav. Ecvol. 70: 187-204.
34. Sundararaj, B.I., Prasad, M.R.N., 1964. The histochemistry of the saccus vasculosus of Notopterus chitala (Teleostei). Quart. J. Micr. Sci., 105: 91-98.
35. Tian, F., Liu, S., Shi, J., Hongfang, Q., Zhao, K., Xie, B., 2019. Transcriptomic profiling reveals molecular regulation of seasonal reproduction in Tibetan highland fish, Gymnocypris przewalskii. BMC Genomics 20: 2.
36. Tsuneki, K., 1986. A Histologic Survey of Diencephalic Circumventricular Organs in Teleosts with Special Reference to Osteoglossomorphs. Japanese Journal of Ichthyology. 33: 27-38.

37. Tsuneki, K., 1992. A Systematic Survey of the Occurrence of the Hypothalamic Saccus Vasculosus in Teleost Fish. Acta Zoologica 73: 67-77.
38. Van de Kamer J.C., Schuurmans A.J., 1953. Development and structure of the saccus vasculosus of Scylliorhinus caniculus (l.). J. Embryol. Exp. Morph. 1: 85-96.
39. Vigh, B., Vigh-Teichmann, I., Aros, B., Varjassy, P., 1972. Licht-undelektronenmikroskopische Untersuchungen des Saccus vasculosus und des Nervus und Tractus sacci vasculosi. Z. Zellforsch. 129: 508-522.
40. Vigh-Teichmann, I., Vigh, B., Aros, B., 1970. Enzymhistochemische Studien am Nervensystem. IV. Acetylcholinesterase Aktivität im Liquorkontaktneuronensystem verschiedener Vertebraten. Histochemie. 21: 322-337.
41. Watanabe., 1966. Light and electron microscope strrdies on the saccus vascrilosus in the ray (Dasrratis akajei). Arch. Histol. Jap. 27: 427449.
42. Yáńez, J., Rodríguez, M.A., Pérez, S., Adrio, F., Rodríguez-Moldes, I., Manso, M.J., Anadón, R., 1997. The neuronal system of the saccus vasculosus of trout (Salmo trutta fario and Oncorhynchus mykiss) : an immunocytochemical and nerve tracing study. Cell Tissue Res. 288: 497-507.
43. Yoshimura, T. 2013. Thyroid hormone and seasonal regulation of reproduction. Front. Neuroendocrinol. 34: 157-166.
44. Zimmermann, H., Altner, H., 1970. Zur Characterisierung neuronaler und gliöser Elementeim Epithel des Saccus vasculosus von Knochenfischen. Z. Zellforsch. 111: 106-126.
45. Zohar, Y., Munoz-Cueto, J.A., Elizur, A., Kah, O., 2010. Neuroendocrinology of reproduction in teleost fish. Gen. Comp. Endocrinol. 165: 438-455.