The Pharma Innovation Journal 2020; 9(6): 538-541

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2020; 9(6): 538-541

www.thepharmajournal.com
Received: 12-04-2020
Accepted: 14-05-2020

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From 3 to 38: diversity of blood groups in fish & Humans- A mini review

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Abstract
Blood group systems in animals arise due to the presence or absence of certain inherited antigens on the surface of their red blood cells. With the first discovery of blood groups in humans in 1900, several other blood groups have been discovered in different animals including fish. The blood group systems have been found in different fish species like goldfish, salmon, tuna, herring, cod, red crucian carp, trout and spiny dogfish. To date, there are shreds of evidence of only three blood groups in fishes: S system for pacific salmon, trout, cod, spiny dogfish and red crucian carp, Tg system for tuna, and Y system for skipjack tuna. In humans, 38 blood group systems are known to exist, 9 of which are considered to be major blood group systems; ABO being the most important. The genes of these blood groups are autosomal, except XG and XK which are X borne, and MIC2 which is present on both X and Y chromosomes. The present paper attempts to review the blood group systems found in fishes in comparison to the diverse blood group systems in humans.

Keywords: Blood grouping, RBCs, fish, S blood type, ABO.

1. Introduction
A blood group is defined as the classification of blood-based on the presence or absence of inherited antigenic substances on the surface of RBCs (Daniels, 2002) [4]. These antigens may be proteins, carbohydrates, glycoproteins, or glycolipids depending on the blood group system. These antigens are genetically determined and can be demonstrated by their specific reaction with antibodies contained in blood serum or anti-serum.
Landsteiner (1900) was the first to demonstrate the occurrence of blood types in humans (Schwarz and Dorner, 2003) [31]. In the same year, Ehrlich and Morgenroth (1900) demonstrated the blood types in goats. Subsequently, blood types in other animals have been demonstrated: cattle, chickens, and whales (Fujino, 1958) [11].

1.1 Blood groups in humans
The emergence of blood groups evolved in humans is still not clear. The geographical distribution of different blood groups dominant in some countries is shown in Figure 1. The first human blood group to be discovered was ABO, by Austrian scientist. It is the most important among 38 blood groups and consists of 4 antigens (A, B, AB, and O). This system is determined by the presence of A and B antigens on the surface of red blood cells and of anti A or anti B antibodies in the serum. The ABO group has a profound influence on hemostasis (Zhang *et al.*, 2012) [42].
The MNS blood group system was discovered by Landsteiner and Levine in 1927. It consists of 46 antigens (Smart and Armstrong, 2008) [34]. Anti M and Anti N antibodies are usually IgM type and are rarely associated with transfusion reaction.
P blood group system was discovered in 1927; with its well-known antigen p1 (Smart and Armstrong, 2008) [34]. Anti P antibodies are produced to high-frequency antigens and it is extremely difficult to find compatible blood for patients requiring blood transfusion.
Rhesus (Rh) system is the second most important blood group system after ABO (Westhoff, 2004) [41]. This system consists of 50 defined blood group antigens out of which only 5 are important.
Lutheran blood group system was discovered in 1945. It consists of 20 antigens. Their function is unknown but can bind extracellular matrix glycoprotein laminin.
Kell blood group system contains over 34 antigens but the major antigens are K or k1 or k or k2.

Kell antigens are highly immunogenic, and anti k is common.
Lewis blood group system was discovered in 1946. Total no of antigens known are 6; out of which only two antigens lea and leb are important (Orntoft, 1991) [22].
Duffy blood group was first isolated from patient Duffy who had hemophilia in the year 1950.This blood group has a total of 6 antigens out of which only 2 are important; Fya and Fyb.
Kidd blood group system is the last major blood group system in humans. It was discovered in 1951 and has a total of 3 antigens among which only 2 are important; Jka and Jkb.
Rest all blood group systems found in humans are minor which include Diego, Yt, Xg, Scianna, Dombrock, Colton, Landsteiner-Weiner, Chido/Rodgers, H, Kx, Gerbich, Cromer, Knops, Indian, Ok, Raph, John Milton Hagen, I, Globoside, Gill, Rh associated glycoprotein, FORS, JR, LAN, VEL, CD59, Augustine, KANNO, and Sid.

1.2 Blood groups in fish

In fish, blood groups are known to exist as they do in humans, although they are unidentical. It has also been found that the frequencies of different blood types vary, depending on the fish population sampled, as in humans. The variation in frequencies is an important tool to study the intermixing of fish populations and to trace the migration of geographic groups (Ford and Gauldie, 1979) [10].
Several studies concerning the possible existence of blood groups in fish have been reported, Noguchi (1903) [20, 21] Toth (1932) [39], but no evidence of blood types was found. Suyehiro (1949) was the first to demonstrate individual antigenic differences in the RBCs of the eel (*Anguilla japonica*) and the gilthead (*Sparus swinhonis*). Cushing and Sprague (1953) [3] studied the agglutination activity for the erythrocytes of several fish species in which they noted considerable antigenic diversity between species but no individual differences within the members of tested species were found.
Major success in the discovery of blood groups in fish happened with Hildemann (1956) [14] who demonstrated the presence of six different antigenic types in goldfish RBCs. Cushing (1956) [1] reported the existence of individual antigenic differences in the oceanic skipjack (*Katsuwonus pelamis*). Cushing and Durall (1957) [2] discovered a blood group system that was found to be analogous to the human ABO system with four antigenic types (i.e., some fish possessed antigen I, some antigen 2, some both antigens and some had neither) in the brown bullhead (*Ictalurus nebulosus*). Suzuki *et al.* (1958) [37] demonstrated the existence of blood groups in species of tunas.
Information concerning the blood group system in tuna was reported by Suzuki, Shimizu, and Morio (1958) [37] which they called the Tg system. This system has two known antigens Tg1 and Tg2 based on which there are 4 blood types: Tg1 type, Tg2 type, Tg1.2 type, and 0 type (lacking both antigens). The evidence for the existence of blood types in Pacific Salmon was given by (Ridgeway and Klontz, 1960). In the following year (1961) [29], Sindermann and Mairs recognized and described the S blood group system in spiny dogfish, *Squalus acanthius.* This system contains at least two antigens, S1 and S2 with individual fish possessing both, either or neither of the antigens, being of blood groups: S1S2, S1, S2, or S0, respectively. Tong and Wu (1993) [38] showed the presence of the S blood group system in red crucian carp, *Carassius auratus* var. A new blood group, called the Y system was discovered in the skipjack tuna, *Katsuwonus pelamis* by Fujino and Kazma, 1968 [12].
Another interesting thing about the fish blood is hemoglobin polymorphism. Multiple forms of hemoglobin named isohaemoglobins have been found in different fish species (Fyhn, 1979; Powers, 1980; Di Prisco and Tamburrini, 1992; De Young *et al.*, 1994; Pérez *et al.*, 1995; De Souza and Bonilla-Rodriguez, 2007) [13, 26, 8, 7, 25, 6]. Most fish hemoglobins like other vertebrate hemoglobins are tetrameric in structure, each molecule composed of four polypeptide chains, also known as globins, each bearing a prosthetic heme group. This heme group is identical in every fish species studied to date while globins differ from species to species and also within the species (De Souza and Bonilla-Rodriguez, 2007) [6]. However, in some primitive fish species such as lampreys and hagfish, monomeric and oligomeric forms of hemoglobin also exist. In the case of lampreys, the oxygenated hemoglobin molecule is a monomer which during deoxygenation undergoes association to form dimers and tetramers. In hagfish (*Myxine glutinosa*), there exist three monomeric hemoglobins in the oxygenated form which during deoxygenation associate into heterodimers and heterotetramers. The hemoglobin polymorphism in fishes may be clarified by two hypotheses: the selectionist theory, explaining the selective advantage of multiple hemoglobins in unstable environments for better gas transportation, and the widely supported neutralist theory, describing neutral mutations as the root cause of hemoglobin heterogeneity (Pérez *et al.*, 1995; Kimura, 1989) [25, 16]. Interestingly, the so-called white-blooded Antarctic icefish are the only known vertebrates to lack both RBCs and hemoglobin (Ruud, 1954) [30].

Table 1: Blood group systems in humans.

S.no.	System name	System symbol	Gene name(s)	Locus	Chromosome	Type
01	ABO	ABO	*ABO*	9	9q34.2	Carbohydrate
02	MNS	MNS	*GYPA,GYPB,(GYPE)*	4	4q31.21	Single-pass protein
03	P1PK/P	P1PK/P	*A4GALD*	22	22q13.2	Carbohydrate
04	Rh	RH	*RHD,RHCE*	1	1p36.11	Multi-pass protein
05	Lutheran	LU	*LU*	19	19q13.32	Single-pass protein
06	Kell	KEL	*KEL*	7	7q34	Single-pass protein
07	Lewis	LE	*FUT3*	19	19p13.3	Carbohydrate
08	Duffy	FY	*DARC*	1	1q23.2	Multi-pass protein
09	Kidd	JK	*SLC14A1*	18	18q12.3	Multi-pass protein
10	Diego	DI	*SLC4A1*	17	17q21.31	Multi-pass protein
11	Yt	YT	*ACHE*	7	7q22.1	GPI-linked protein
12	Xg	XG	*XG,MIC2*	X	Xp22.33	Single-pass protein
13	Scianna	SC	*ERMAP*	1	1p34.2	Single-pass protein
14	Dombrock	DO	*ART4*	12	12p12.3	GPI-linked protein

15	Colton	CO	*AQP1*	7	7p14.3	Multi-pass protein
16	Landsteiner-Wiener	LW	*ICAM4*	19	19p13.2	Single-pass protein
17	Chido/Rodgers	CH/RG	*C4A,C4B*	6	6p21.3	Absorbed from plasma
18	H	H	*FUT1*	19	19q13.33	Carbohydrate
19	Kx	XK	*XK*	X	Xp21.1	Multi-pass protein
20	Gerbich	GE	*GYPC*	2	2q14.3	Single-pass protein
21	Cromer	CROM	*CD55*	1	1q32.2	GPI-linked protein
22	Knops	KN	*CR1*	1	1q32.2	Single-pass protein
23	Indian	IN	*CD44*	11	11p13	Single-pass protein
24	Ok	OK	*BSG*	19	19p13.3	Single-pass protein
25	Raph	RAPH	*CD151*	11	11p15.5	Multi-pass protein
26	John Milton Hagen	JMH	*SEMA7A*	15	15q21.1	GPI-linked protein
27	I	I	*GCNT2*	6	6p24.2	Carbohydrate
28	Globoside	GLOB	*B3GALT3*	3	3q26.1	Carbohydrate
29	Gill	GIL	*AQP3*	9	9p13.3	Multi-pass protein
30	Rh-associated glycoprotein	RHAG	*RHAG*	6	6p21	Multi-pass protein
31	FORS	FORS	*GBGT1*	9	9q34.13	Carbohydrate
32	JR	JR	*ABCG2*	4	4p22	Multi-pass protein
33	LAN	LAN	*ABCB6*	2	2q36	Multi-pass protein
34	VEL	VEL	*SMIM1*	1	1p36.32	
35	CD59	CD59	*CD59*	11	11p13	Single-pass protein
36	Augustine	AUG	*SLC29A1*		6p21.1	GPI-linked protein
37	KANNO	PRNP			20p13	Multi-pass protein
38	Sid				17q21.32	Prion protein

2. Conclusion:

Since the discovery of first human blood groups (ABO) by Karl Landsteiner in 1900, other blood groups (38 at present) were gradually discovered from 1927. However, very little is known about the significance of blood polymorphism in humans. When compared to humans, there have been relatively few published studies concerning the possible existence of blood types in fishes. The demonstration of various blood group systems especially in fish, as outlined in this paper, can serve as valuable tools for fisheries management and conservation. Nevertheless, more research regarding the blood types in fish needs to be done in time to come.

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