INTRA-UTERINE SELECTION DUE TO MATERNAL-FETAL INCOMPATIBILITY OF BLOOD TYPES IN THE WHALES*

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Since its discovery, it had been generally considered that blood type was hereditarily neutral characteristics free from natural selection. Thereafter many observations were reported on the correlations between blood types and hemolytic diseases in newborn or erythroblastosis foetalis and differential survival in intra-uterine life such as rate of fertility and of miscarriage and in extra-uterine life for human and some other mammalian species (reviewed in Race and Sanger, 1959, pp. 310–312). These knowledges have led to rise of discussions on natural selections relating to blood groups. Series of recent papers on human blood groups by Matsunaga (1953, 1954, 1959), Matsunaga and Itoh (1953, 1954, 1958), Simmons et al. (1960), Grubb and Sjöstedt (1955), and Jakobowicz et al. (1961) furnish more evidences from these view-points. Basing upon the results of the Antarctic whaling investigation in 1960/61 season, Fujino (1962) describes that differential percentage pregnancies by blood groups were seen in both species of the Antarctic pigmy-blue and the fin whales, and that hemolytic antibodies were positively detected from isoserums of fin whales. Then he states that the facts in these observations strongly suggest incidence of miscarriages of fetuses caused by maternal-fetal incompatibility of blood types in whales and that these frequencies of occurrence will closely relate to gene frequencies of blood types of the population. Results of further observations in 1961/62 Antarctic season (Fujino, unpublished data) confirm the differential rates of pregnancy stated above. In the present paper, at first are described the results of observation, that is a) differential apparent rates of pregnancy by blood groups and b) hemolytic properties of isoserums as the evidences suggesting intra-uterine selection in whales. Secondly, after basing upon knowledges about intra-uterine selection and its compensatory mechanism in human (Matsunaga, 1954), quantitative relationships between selection and fitness are discussed, and the prenatal mortality rate is estimated for actual population of whales.

MATERIALS AND METHODS

Testing bloods All stages of testing bloods were performed on board for fresh samples, and the methods of typing blood are same as that described in the previous paper (Fujino, 1962). In addition, hemolytic antibodies were detected for isoserums as follows. To each test-tube containing a series of successive dilutions of inactivated fresh isoserum was added equal volume of 2% cell suspension, and mixtures were incubated at 37°C. Thirty minutes later, reading was made. In-

* Dedicated to Professor T. Ogawa for his sixtieth birthday

direct Coomb's Test (I.C.T.) was undertaken as follows (refer Race and Sanger, 1959). To each tube containing two drops of a series of succesive dilutions of iso-serum was added equal volume of 2% cell suspension, and mixtures were incubated at 37°C for one hour. After being washed three times with cool saline, two drops of 1 : 10 diluted immune rabbit antiserum, prepared by injecting fin whale serum, were added to the coated cells. Ten minutes later, results of reactions were observed.

Observing ovary and internal reproductive organ of female whales As it is generally considered that corpus albicans survive on ovary throughout life of female whale even after diminishing in size (Mackintosh, 1929 and Laws, 1961), one can know accumulated number of past ovulation for each individual by counting the ovarian corpora. When carcases of female whales were treated on board, ovaries were taken out and were observed. Individuals, of which existence of ovarian corpora were positively detected, were recognized as sexually mature. Simultaneous observations on uterine conditions were made to discriminate pregnancy or not. Female, from which fetus was found in their uterus, always possesses functional corpus luteum in the ovaries. Sometimes, however, observation encounters females from which no fetus was found in spite of existence of functional corpus luteum in their ovaries. These are generally interpreted to correspond with one of following three cases, that is, 1) the corpus is originated from mere ovulation without fertilization, 2) tiny embryo at a very younger stage of conception was missed or 3) it has not passed so long time since fetus had been lost because of shock when killed or of physiological factors. For some individuals of females additional observations were made by author himself for intra-uterine conditions especially for degree of congestion of mucous membrane.

EVIDENCES SUGGESTING INTRA-UTERINE SELECTION RELATING TO BLOOD GROUPS

First of all, problems identifying breeding subpopulations should be discussed here. After studying summarized results of marking return including those taken after his previous work (Brown, 1954), Brown (1962) stated as follows. " Marks from fin whales do suggest that fin whales from different breeding-populations may intermingle on the feeding-grounds, and that the ' groups ' of whales within the whaling Areas may include animals belonging to more than one breeding population. Thus, sector of area III which lies to the south of South Africa has been shown to contain during the southern summer fin whales from the populations of the South Atlantic and Indian Oceans." Fujino (1962) extends blood typing investigation, which was undertaken to identify breeding population of the North Pacific fin whales (Fujino, 1960), to the Antarctic fin whales, and states that " The frequency of occurrence of Ju blood types of finbacks suggested that a portion of the Atlantic population from area II migrates to area III and mingles with the population there." Frequencies of occurrence of Ju2-positive types were estimated approximately as 2 per cent for the aboriginal population of the area III and as

30 per cent for the postulated Atlantic population which partly contribute to the stocks in the area III, and estimation of intermingling ratio between both populations were made for the sample taken from area III in 1960/61 season. Results of further investigation in 1961/62 confirm existence of geographical non-random distribution of frequency of occurrence of blood types stated above, and suggest existence of the additional different populations in the area IV of which frequency of occurrence of Ju2-positive types reveals somewhat higher figure than that of aboriginals in the area III (Fujino unpublished data). These might support the already-cited knowledges which was noted by Brown (1962). When various parameters for population study were obtained from area in which migratory ranges of different populations overlapped each other, the figures should be separated into those proper to each pure population. Figures for the postulated Atlantic population in Table 1 were obtained by summarizing data on several days in which daily incidence of Ju2-positive blood types jumped up significantly (refer Fujino, 1962).

TABLE 1. FREQUENCY OF OCCURRENCE OF FIN WHALE Ju MAJOR BLOOD TYPES IN THE AREA III OF THE ANTARCTIC*

Blood type		Postulated Atlantic Population**	Geographical area*** B	A	C
Percentage of Ju2-negative type	Ju1	69.7	91.2	95.4	98.0
Percentage of Ju1-2 heterozygote	Ju1·2	25.0	7.5	4.0	2.0
Percentage of Ju2 homozygote	Ju2	5.3	1.3	0.6	0.0
Total numbers of whales typed		132	734	350	104

* Cited from Fujino (1962)

** Sum of the data of days in which the frequency of occurrence of Ju2-positive types jumped to high frequencies of approximately 30 per cent.

*** Arbitrarily divided as follows ; section A : 35 to 70 degrees east of south of 50 degrees south ; section B : 0 to 35 degrees east of south of same ; section C : north of 50 degrees south.

Here some results of observation can be adduced as evidences suggesting intra-uterine selection relating to blood groups. As already reported by Fujino (1962) no significant differences was seen in frequency of occurrence of blood types between both sexes, but marked differences in the percentage of pregnant whales among mature females were recognized between Ju2-positive and Ju2-negative blood groups in the pigmy-blue and the fin whales. These relationships were confirmed with results of further investigation in 1961/62 season (Fujino, unpublished data). Table 2 shows these figures obtained in the season 1960/61 for different geographical areas and for the postulated Atlantic population. Although fin whale bloods were classified into seven types in all by subgrouping Ju2 antigen complex (Fujino, 1962), in Table 2 comparisons of percentage incidence of pregnant female are shown for three major groups alone, because of scantiness of data for subdividing. It can be seen from this table that percentage incidence of pregnant whales among mature

females reveals lower figure in Ju1 group than that in Ju2-positive groups. Similar type of observations were reported for human already. For instance, basing upon his observations on marked differences of rate of miscarriage between compatible and incompatible matings for ABO blood groups, Matsunaga and Itoh (1954) state that there should be differential natality rates between these two types of

TABLE 2. DIFFERENCE OF PERCENT OF PREGNANCY BY BLOOD TYPES AMONG ADULT FEMALE WHALES*

Blood type	Fin whale				Pigmy-blue whales
	Postulated Atlantic population	B	A	Sum of A and B	
Ju2-positives	78.9(19)**	73.3(30)	40.0(5)	68.6(35)	71.4(7)
Ju2-negatives	63.9(36)	61.6(307)	51.5(101)	59.1(408)	32.8(61)

* Cited from Fujino (1962) ** Figures in parentheses show number of samples typed.

matings. Basing upon data collected at maternity hospitals, Boorman (1950) and Bryce et al. (1950) find with regard to compensatory mechanisms against intrauterine selection that rate of conception in mother population reveals the highest figure in AB group than those in any other three groups belonging to ABO blood group system. According to analogical construction from these phenomena in human being, above-stated observations in whales might suggest that there should be significant differences by blood types in the rates of fertilization or of miscarriage or in both.

As alredy reported by Fujino (1962) most donors classified as Ju1 type homozygote have anti-Ju2 isoantibodies in their serum, and moreover isoantibodies are positively detected with reference to three kinds of Ju2 specificities in fin whales.

TABLE 3. TITRATION OF ISOAGGLUTININ OF FIN WHALE, NOT INACTIVATED*

cells of: type	no.	no. 313 serum** 16	32	64	128	256
Ju1	313	−	−	−	−	−
Ju1·2_3	394	++	++	+	−	−
Ju1·2_2	403	++	++	++	++	+
Ju1·2_1	349	++	++	++	++	+

cells of: type	no.	no. 1374 serum** 4	8	16	32	64
Ju1	1275	−	−	−	−	−
Ju1·2_3	1279	++	+	−	−	−
Ju1·2_2	1301	++	++	++	+	−
Ju1·2_1	1348	++	++	++	++	+

cells of: type	no.	no. 1161 serum*** 8	16	32	64	128
Ju1	1275	−	−	−	−	−
Ju1·2_3	1279	−	−	−	−	−
Ju1·2_2	1301	++	++	+	−	−
Ju1·2_1	1348	++	++	++	++	+

cells of: type	no.	no. 121 serum 1	2	4	no. 368 serum 1	2	4
Ju1	313	−	−	−	−	−	−
Ju1·2_3	394	−	−	−	−	−	−
Ju1·2_2	403	−	−	−	++	+	−
Ju1·2_1	349	++	+	−	++	++	+

* Blood types of these donors are Jul (nos. 313 and 1374), Ju 1·2_3 (nos. 368 and 1161) and Ju 1·2_3 (no. 121).

** Specific hemolysis were observed up to dilutions 1 : 8 in no. 313 serum and 1 : 2 in no. 1374 serum against Ju 2 positive cells.

*** Specific hemolysis was observed at dilutions 1 : 1 through 1 : 4 against nos. 1301 and 1348 cells.

That is, $Ju2_3$ subtype donors had isoantibodies for $Ju2_1$ and $Ju2_2$, $Ju2_2$ donors had isoantibody for $Ju2_1$, while $Ju2_1$ had no isoantibody. Table 3 shows titrating results for several examples of these isoserums. No isoserum for Ju1 has been discovered. Most fresh isoserums possessing antibodies specific to Ju2, derived from Ju1 type donors, agglutinated $Ju2_1$ cells at dilutions ranging from 1 : 2 to 1 : 256 and hemolysed at dilutions between 1 : 1 and 1 : 16 when not inactivated. However, two examples of isoserums taken from Ju1 type female donors (nos. 301 and 347), which have ovaries with functional corpus luteum and congested uterus but lack fetus, revealed marked high titer. Table 4 shows comparisons of agglutinin

TABLE 4. COMPARISON OF AGGLUTININ TITER OF ISOANTIBODIES OF JU 1 TYPE OF FIN WHALES AT VARIOUS PHYSIOLOGICAL CONDITIONS, EXAMINED BY INDIRECT COOMB'S TEST (I.C.T.)

Physiological condition			no. of samples examined	range of titer*
male	mature		8	1 : 4～1 : 512
female	mature,	resting	5	1 : 4～1 : 512
〃	〃	pregnant	9	1 : 4～1 : 1024
〃	〃	non-pregnant, but with functional corp. lutea, excluding nos. 301 & 347	11	1 : 4～1 : 1024
〃	〃	〃 no. 301**	1	1 : 2048
〃	〃	〃 no. 347**	1	1 : 4096

* Tested against $Ju2_1$ homozygote cells. The rabbit serum prepared by injecting fin whale serum does not agglutinate whale cells at dilution used.

** Probable abortive 2 females out of 13 samples with a functional corpus luteum in their ovary but lacking fetus.

titer by different physiological conditions for these anti-Ju2 isoantibodies derived from Ju1 type donors. Titrations of isoserums were made by means of Indirect Coomb's Test (I.C.T.). These observations suggest that titers of isoantibodies of the Ju1 mothers have risen by isoimmunization between fetus and mother which followed conception of Ju2-positive fetus and that subsequently the fetus seemed to be miscarriaged by hemolytic diseases some time before the mother whale was captured.

No other anatomical observation has been made for this problem at present. While it has not been solved yet how soon do the enlarged and congested uterus regress and do functional corpus luteum diminish into corpus albicans. If these physiological regression would be accomplished in a comparable shorter interval, it might be reasonable to presume that a very limited number of miscarriages are anatomically confirmed at present, even if extensive observations are attempted.

Above-stated facts suggest that intra-uterine selections occur at fairly high frequency in incompatible mating of Ju1 female × Ju2-positive male. Though no direct evidence suggesting selection in another incompatible mating of Ju2 female × Ju1 or Ju1·2 male has been obtained, it can be assumed that this selection might

occurs at lower frequency than in the former incompatible mating in the recruiting generation in all, because 1) no isoantibody for Ju1 has been found in the serums of Ju2 donors, and 2) Ju2 homozygote has very low frequency of occurrence in the population.

In the case of human beings, differential natality rates between incompatible and compatible matings can be observed after second conception of each individual for Rh blood group system, but even in first conception already for ABO system. It is thought to closely relate to these facts that natural isoantibodies for Rh factor occur irregularly at low frequency, while those for A or B factor occur always in connection with existence of erythrocyte antigens (Matsunaga, 1959). As already stated, most Ju1 type donors have isoantibodies specific to Ju2 in fin whales, so that it can be surmised that intra-uterine selection in this species occurs already even in first conception, although no available observation has been made so far.

RELATIONS BETWEEN FREQUENCIES OF OCCURRENCE OF BLOOD TYPES AND OF INTRA-UTERINE SELECTION

Fujino (1962) states that prenatal mortality rate due to intra-uterine selection will closely depend upon the frequency of occurrence of Ju blood groups. Analysis of these quantitative relationships will be attempted in this paragraph. First of all genetic relationships should be discussed. After considering far lower figures in relative frequency of occurrence of Ju1·2 heterozygote against those which are expected from hypothetical two allelic system for random mating population and parentages between mother and fetus, Fujino (1960) proposed that three allelic genes including a dominant or recessive gene will be involved in the Ju blood group system for the north Pacific fin whale population. In the results of investigation for the Antarctic fin whale population, however, observed figures of relative frequency for major three blood groups are well consistent with those which are expected from major two equal allelic genes for the random mating population (see Table 1). Furthermore, it became to be obvious that Ju2 antigen was subdivided into three kinds of subtypes, so that it can be assumed so far that four allelic genes including one (j1) for Ju1 antigen and three ($j2_1$, $j2_2$ and $j2_3$) for Ju2 antigen complex equal each other are involved for Ju blood group system of the Antarctic fin whales. According to this hypothesis phenotype-genotype relationships can be expressed as those in Table 5. As shown in Table 3, differential intensity in agglutination reaction is observed among these three subtypes for the same reagent, and some evidences have been obtained which suggest existence of subtypes among Ju2-positive groups for the North Pacific whales also (Fujino, 1960, Table 7). These facts may lead neccesity in future to re-consider allelic system and biases in relative phenotypic frequency which may be reflected by existence of subtypes and dosage effect. In Table 5 are shown relative frequencies of three major phenotypes in the random mating population, where summarized frequency of allelic genes $j2_1$, $j2_2$ and $j2_3$ controlling three specificities of Ju2 antigen complex is q and that of j1 is p.

Secondly, should be noted definition of compatible-incompatible relationships

of pregnancy or mating in relation to blood groups of whales. According to Matsunaga (1959), incompatible pregnancy means a case which erythrocytes of cow does not possess an antigen, which is hereditarily derived from bull and exists in fetal blood. All other cases belong to compatible pregnancy. Incompatible mating is the combination which may cause incompatible pregnancy, and other combinations

TABLE 5. PHENOTYPE-GENOTYPE RELATIONSHIPS FOR THE ANTARCTIC FIN WHALE JU BLOOD TYPES UNDER A HYPOTHETICAL ALLELIC SYSTEM

Phenotype		Genotype	Frequency of occurrence in* the population at Hardy-Weinberg's Equilibrium
Ju2-negative	Ju1	j1 j1	p^2
Ju2-positive	Ju1·2_3	j1 $j2_3$	2 pq
	Ju1·2_2	j1 $j2_2$	
	Ju1·2_1	j1 $j2_1$	
	$Ju2_3$	$j2_3$ $j2_3$	q^2
	$Ju2_2$	$j2_3$ $j2_2$, $j2_2$ $j2_2$	
	$Ju2_1$	$j2_3$ $j2_1$, $j2_2$ $j2_1$, $j2_1$ $j2_1$	

* Freq. of occurrence of j1 gene is p, summarized freq. of $j2_1$, $j2_2$ and $j2_3$ is q, and amount to 1.

belong to compatible mating. Table 6 shows these compatible-incompatible combinations related to major three phenotypes of Ju blood group system. As available data are not sufficient to analyse the problems under considering for subtypes, following discussions in the present paper will be undertaken in accordance with combinations in Table 6.

TABLE 6. COMPATIBLE-INCOMPATIBLE PREGNANCIES AND MATINGS IN FIN WHALE JU MAJOR THREE BLOOD TYPES

pregnancy				mating	
compatible		incompatible		compatible	incompatible
mother	fetus	mother	fetus	female male	female male
Ju1	Ju1	Ju1	Ju1·2	Ju1 ×Ju1	Ju1×Ju1·2
Ju2	Ju2	Ju2	Ju1·2	Ju2 ×Ju2	Ju1×Ju2
Ju1·2	Ju1	—		Ju1·2×Ju1	Ju2×Ju1·2
Ju1·2	Ju1·2	—		Ju1·2×Ju1·2	Ju2×Ju1
Ju1·2	Ju2	—		Ju1·2×Ju2	—

Next problems to be considered are compensatory mechanisms against selection for heterozygotes. Phenotype to be selected disadvantageously by maternal-fetal incompatibility of blood types is always heterozygous fetus to be born from incompatible matings. This means that equal numbers of two kinds of major allelic genes controlling antigens Ju1 and Ju2 eliminate from the population in each occasion of selection. If this phenomenon would merely progress, gene frequency of the population should promptly shift and in consequence will be attained monomorphism consisting of one gene which had higher frequency at the ancestral population. In real natural population, however, polymorphism is generally maintained.

Regarding to these facts Matsunaga and Itoh (1954) state that the mortality rate of eliminating heterozygotes is so high that mutation could not sufficiently compensate the losses of genes in each generation. At present following several phenomenon are discussed in population genetics for human blood groups as the possible mechanisms for maintaining polymorphism.

a) Excessive natality rate of heterozygous fetus in compatible mating: After reporting excessive natality of MN type child in the mating of MN mother × MN father and of AB type child in the mating of AB mother × AB father in human, Matsunaga (1954) states that heterozygous fetuses are disadvantageouly selected in incompatible mating, while in compatible mating number of this type of child which are actually born exceeds expected figure. Though sufficient evidences suggesting these similar phenomena have not been obtained yet in whales because of scantiness of data, it might be interpreted that differential rates of pregnancy between Ju1 and Ju2-positive blood groups which was described in the previous paragraph might consist of two elements of decline by intra-uterine selection in Ju1 group cows and of excessive natality of Ju1·2 heterozygous calves in Ju1·2 heterozygous cows, if similar trends would be involved.

b) Selective interaction between different blood group systems: After partitioning the matings, that had produced miscarriages or stillbirths, by MN and ABO incompatibility jointly of human blood groups, Matsunaga (1960) found a significant excess in the MN compatible, ABO incompatible mating and states that this might suggest that selection of heterozygous child due to ABO incompatible tend to occur more frequently in compatible mating than in incompatible mating relating to MN blood group system. Although no information relationg to the similar type of facts has been available yet in whales, it must be important problem to be discussed in subsequent studies. Additional several observations were reported in relation to blood group and span of life for human being (Allan, 1953 a, 1953 b), but sufficient observations have not been available yet in whales.

According to the above-stated discussions, there are some differences of relative fitness in intra-uterine life between different phenotypes especially heterozygote and homozygotes, and then it can be thought that gene frequencies of a population are maintained by counterbalance between selection in incompatible mating and excessive natality in compatible mating for heterozygotes. If interactions between different blood group systems and some other factors could be thought to hardly influence upon selective and compensatory mechanisms, selective value and relative fitness could be calculated as follows. When selective value for heterozygous fetuses in incompatible mating are given as k and k' for two cases of which blood groups of cows are Ju1 and Ju2 homozygotes respectively and relative fitness is given as $1+K$ for heterozygote in compatible mating, incidence of intra-uterine selection are expressed as $q.k$ and $p.k'$ for the former two cases and excessive natality rate is $K/2$ for the latter case, so that condition maintaining equilibrium for gene frequencies of a population is given by following formula.

$$[\mathrm{Ju1}]\ k.q + [\mathrm{Ju2}]\ k'.p = [\mathrm{Ju1{\cdot}2}]\ K/2 \quad \ldots\ldots\ldots\ldots\ 1)$$

, where $1 \geqq k$, $k' \geqq 0$, $K \geqq 0$, and [Ju1], [Ju1·2] and [Ju2] mean relative frequency of occurrence for each phenotype, and amount to 1 in all. As survivor of fetuses at the end of intra-uterine life are given by:

$$[\mathrm{Ju1}]\left\{[\mathrm{Ju1}]+\frac{[\mathrm{Ju1}\cdot 2]}{2}(2-k)+[\mathrm{Ju2}](1-k)\right\} \text{ for Ju1 homozygote cows,}$$

$$[\mathrm{Ju1}\cdot 2]\frac{2+K}{2} \text{ for Ju1·2 heterozygote cows,}$$

$$\text{and } [\mathrm{Ju2}]\left\{[\mathrm{Ju1}](1-k')+\frac{[\mathrm{Ju1}\cdot 2]}{2}(2-k')+[\mathrm{Ju2}]\right\} \text{ for Ju2 homozygote cows}$$

respectively, ratio between P1 and P2 which mean apparent rates of pregnancy in Ju1 and Ju2-positive types of cows is expressed as follows.

$$\mathrm{P1/P2}=\frac{\{[\mathrm{Ju1}\cdot 2]+[\mathrm{Ju2}]\}\left\{[\mathrm{Ju1}]+\frac{[\mathrm{Ju1}\cdot 2]}{2}(2-k)+[\mathrm{Ju2}](1-k)\right\}}{\frac{[\mathrm{Ju1}\cdot 2]}{2}(2+K)+[\mathrm{Ju2}]\left\{[\mathrm{Ju1}](1-k')+\frac{[\mathrm{Ju1}\cdot 2]}{2}(2-k')+[\mathrm{Ju2}]\right\}} \quad \cdots\cdots 2)$$

As regards relations between k and k', it seems to be reasonable to assume as $k \geqq k'$, judging from the facts that anti-Ju2 isoantibody is positively detected from serums of most Ju1 type donors while no isoantibody for Ju1 has been detected from Ju2 type donors. Then after applying the observed figures, which are shown in Tables 1 and 2, to Formulae 1 and 2, calculations were attempted for five cases of $k' = k$, $1/2k$, $1/4k$, $1/8k$ and $0 \ll k$. Parameters to be used in the present discussions should be those which were obtained from a pure population. For this purpose figures for the postulated Atlantic population of which Ju2-positive types occur in fairly high frequency are most appropriate at present, that is, $[\mathrm{Ju1}] = 0.697$, $[\mathrm{Ju1}\cdot 2] = 0.250$, $[\mathrm{Ju2}] = 0.053$, $p = 0.822$, $q = 0.178$ and $\mathrm{P1/P2} = 0.639/0.789 = 0.810$. Percentage pregnancies for each blood group used here were obtained during Antarctic pelagic whaling season in which whales migrate there for feeding. It is generally accepted that pelagic whaling season does hardly overlap the seasons for copulation and parturition for the southern whales (Mackintosh and Wheeler, 1942, Laws, 1961). It may be thought therefore that this relative figure of percentage pregnancies between different blood groups obtained during whaling season approximately represent that of real population, even if female whales belonging to a population somewhat segregate by age or some other physiological factors during their migration to feeding grounds. The results of calculation are shown in Table 7. According to this table, figure of k shows an approximate constant of 0.37 for any cases of relations between k and k'. While, figure of k' fluctuates at ranges between 0.000 and 0.373 and K at ranges between 0.368 and 0.500. This figure of k means that prenatal mortality rate of heterozygous fetuses expected from Ju1 type mother whales at incompatible mating reach up to approximately 37 percent for the postulated Atlantic population. This figure corresponds approximately twice as the mortality rate of heterozygous A or B child at the matings of mother O×father A or mother O×father B (Matsunaga and Itoh, 1954).

TABLE 7. CALCULATED FIGURES OF VARIOUS PARAMETRES FOR THE INTRA-UTERINE SELECTION OF FINBACK WHALES

	relation between k and k'	k*	k'*	$1+K$**
i	$k' = k$	0.373	0.373	1.500
ii	$k' = 1/2k$	0.371	0.186	1.433
iii	$k' = 1/4k$	0.370	0.093	1.401
iv	$k' = 1/8k$	0.369	0.046	1.384
v	$0 \fallingdotseq k' \ll k$	0.371	0.000	1.368

* selective values of heterozygous fetuses expected from Ju1 and Ju2 mother whales at incompatible matings.

** relative fitness of heterozygous fetuses expected from Ju1·2 mother whales at compatible mating.

In the next place will be discussed general relationships between gene frequency and rate of intra-uterine selection of heterozygotes at incompatible mating in a population which gene frequencies are given as p and q controlling Ju1 and Ju2 antigens respectively, prenatal mortality rate (d) of heterozygous fetuses can be expressed as the summarized figure for two cases which blood groups of cows are Ju1 and Ju2 homozygotes.

$$d = [\mathrm{Ju1}]\, q.k + [\mathrm{Ju2}]\, p \cdot k' \quad \ldots\ldots 3)$$

As the relations of $p = 1-q$, $[\mathrm{Ju1}] = (1-q)^2$ and $[\mathrm{Ju2}] = q^2$ can be adopted to a random mating population, Formula 3 will be arranged for q as follows,

$$d = q\,\{(k-k')q^2 + (k'-2k)q + k\} \quad \ldots\ldots 4)$$

, where $1 \geqq q > 0$. When being differentiated by q, Formula 4 will be

$$d' = 3(k-k')q^2 + 2(k'-2k)q + k \quad \ldots\ldots 5)$$

Mortality rate d will take a maximum figure at a point of

$$q = \frac{2k-k'-\sqrt{k^2-kk'+k'^2}}{3(k-k')} \quad \ldots\ldots 6)$$

, where $1 \geqq q > 0$ and $1 \geqq k \geqq k' \geqq 0$.

Formulae showing relations between gene frequencies (p, q) and prenatal mortality rate (d) and figure of q at which d takes a maximum will be obtained from Formulae 4 and 6 for five cases of relations between k and k', presented already, as follows.

$$\left.\begin{array}{llll} \text{i)} & \text{When } k' = k & d = q(1-q)k & \text{takes a maximum at } q = 0.500 \\ \text{ii)} & \text{,,} \quad = 1/2k, & = q(1-q)(2-q)k/2 & \text{,,} \quad = 0.423 \\ \text{iii)} & \text{,,} \quad = 1/4k, & = q(1-q)(4-3q)k/4 & \text{,,} \quad = 0.362 \\ \text{iv)} & \text{,,} \quad = 1/8k, & = q(1-q)(8-7q)k/8 & \text{,,} \quad = 0.355 \\ \text{v)} & \text{,,} \quad 0 \fallingdotseq k' \ll k, & = q(1-q)^2 k & \text{,,} \quad = 0.333. \end{array}\right\} \quad \ldots 7)$$

When figures of k in Table 7 are put into Formula 7, relations between d and q will be drawn as Fig. 1. According to Fig. 1 prenatal mortality rate takes a maximum figure at a point of $q = 0.500$ for a case of $k = k'$ (curve 1) and reaches up to more than 9 percent of total recruiting generation of the population. In the postulated Atlantic population ($p = 1-q = 0.822$) the figure of d is approximately 5 percent for any cases of relations between k and k'. If various parameters in Table 7 could be available for the aboriginal population of area III too, the figure of d might be es timated to not reach up more than 0.3 or 0.4

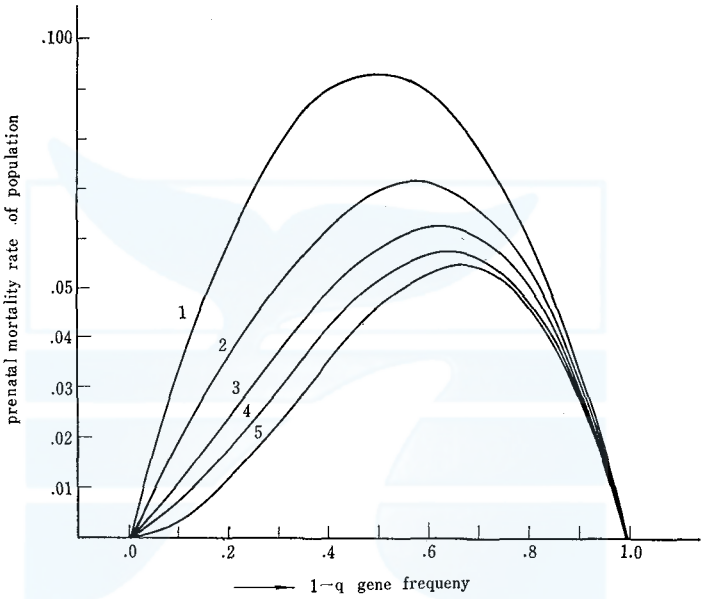

Fig. 1. Relation between blood type gene frequency and frequency of occurrence of intra-uterine selection of heterozygous fetuses in randon mating ideal population of whales. Curves 1, 2, 3, 4 and 5 correspond to five cases of which relations between k and k' are $k' = k$, $= {}^1/_2 k$, $= {}^1/_4 k$, $= {}^1/_8 k$ and $\fallingdotseq 0 \ll k$ respectively.

percent for the population. These figures include mortality rate at intra-uterine life only. Actually, however, perinatal mortality rate of recruiting generation must be enhanced with postnatal death of infants which is observed in human as fatal hemolytic diseases which follow incompatible pregnancies.

SUMMARY

Basing upon the results of blood typing investigation, the author stated in his previous paper (Fujino, 1962) that in the area III of the Antarctic distribute at least two different breeding populations of fin whales which have different frequencies of occurrence of blood type each other, and that this might support the results of marking investigation reported by Brown (1954). Furthermore after discussing

relations between blood groups and other items of investigation, he described that significant differences were seen in the percentage pregnancy among mature females by blood groups. This suggest that intra-uterine selection caused by maternal-fetal incompatibility of blood types, which has been reported for human beings and some other mammalian animals, takes place in whales also.

In the present paper, at first results of serological observation, that is, existence of natural isoantibodies, their hemolytic properties and marked ascending of titre of the isoantibody which seems to be caused by isoimmunization between fetus and mother are described as evidences relating to intra-uterine selection. Secondly, after basing upon an assumption of compensatory mechanisms for intra-uterine selection, quantitative relationships are discussed between frequency of occurrence of blood types and relative rates of pregnancy by blood groups, and estimation for the rate of incidence of the selection was made. Consequently, the author noted that in the postulated Atlantic population approximate 37 percent of heterozygous fetuses expected from Ju1 type females at incompatible mating were disadvantageously selected, and this figure correspond to approximate 5 percent of the recruiting generation of the population and this does not reach up more than 0.3 or 0.4 percent in the aboriginal population of the area III.

ACKNOWLEDGEMENTS

The author is indebted to Dr. H. Omura, Director of the Whales Research Institute, Tokyo for orienting this study and to Dr. E. Matsunaga at the National Institute of Genetics, Mishima for his valuable comments. Dr. S. Tanaka at the Tokai Regional Fish. Lab. gave the author pertinent advices in introducing the formulae. Thanks are also due to the officers and the crews of the whaling factory ship, Kyokuyo-maru No. 2, who gave the author facilities and assistance.

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