THE ABO BLOOD GROUP FREQUENCY DISTRIBUTION OF SINGAPORE BASED ON A BLOOD DONOR SAMPLE

By K. T. Chan, M.B.,B.S., F.R.C.S., F.R.C.S.E.

(From the Department of Surgery, University of Singapore)

HISTORICAL

In 1900 Landsteiner published his discovery of the ABO blood groups. He found that human beings could be divided into four groups depending upon the agglutination reactions between their red cells and normal human sera. The intensive practical application of this discovery in the field of blood transfusion has led to very extensive study of the ABO blood groups and the discovery of eight other blood group systems up to the present time. These various systems are given in Table I.

The discovery of the ABO blood group system is of vital importance in blood transfusion. The discovery of the Rhesus system in 1940 (Landsteiner and Wiener) brought about a completely new understanding of the group of diseases due to blood incompatibilities. It has since been shown that several other blood group systems can give rise to haemolytic disease. Von Dungen and Hirszfeld (1910) showed that blood groups are inherited as Mendelian characters and in 1918, Hirszfeld and Hirszfeld demonstrated that the ABO blood group frequencies vary widely from one population to another. These observations together with the discovery of the other blood group systems are now widely used in anthropology in the study of racial classification of human populations. The regularity of inheritance of these various blood group systems has also made them the most widely used tool in the study of human genetics and in the solution of problems of identity, parentage and paternity.

In 1953 Aird, Bentall and Roberts showed that people of blood group A have a higher incidence of carcinoma of the stomach than people in the other blood groups. This observation has opened a new field in the study of the part blood group genes play in the aetiology of diseases. Several diseases have now been tested for any relationship to blood groups and some of them have been shown to be strongly related to particular blood groups. Much work is being done in this field the results of which are outside the scope of this short review.

AVAILABLE ABO DATA ON MALAYAN ETHNIC GROUPS

A voluminous amount of data is available on the ABO frequencies for most parts of the world but the published data on Malays, Chinese, Indians and Eurasians in Malaya and Singapore are relatively meagre. Mourant et al in 1958 surveyed the published world data on ABO frequencies and found that it covered a total of about 6,000,000 people. Of this vast total, only 7,013 were of Malayan peoples including 1,214 among the aborig'nes of Malaya.

TABLE I. THE BLOOD GROUP SYSTEMS

No.	Blood Group System	Discovered by	Year
1	ABO A_1 A_2 Subdivisions	Landsteiner	1900 1911
2	MN MNs Subdivisions	Landsteiner & Levine	1927 1947
3	P P_1 P_2 Subdivisions	Landsteiner & Levine	1927 1955
4	Rh (Numerous subsequent subdivisions)	Landsteiner & Wiener	1940
5	Lutheran	Callender, Race & Paykoc	1945
6	Kell	Coombs, Mourant & Race	1946
7	Lewis	Mourant	1946
8	Duffy	Cutbush, Mollison & Parkin	1950
9	Kidd	Allen, Diamond, Niedziela	1951

TABLE II. PUBLISHED DATA ON ABO FREQUENCIES OF NON-ABORIGINAL MALAYAN POPULATIONS UP TO 1961.

Place	Population	Authors	No.	O	A	B	AB
Perak	Malay	Schebesta, (1952)	44	15	9	19	1
Singapore	Malay	Mourant et al, (1953)	42	17	7	17	1
Singapore	Malay	Allen & MacGregor, (1947)	1,963	794	521	504	144
Singapore	Chinese	Allen & MacGregor, (1947)	624	269	150	173	32
Malaya	Chinese	Simmons et al, (1950)	250	116	63	52	19
Singapore	Chinese	Yeoh, (1960)	1,000	443	255	265	37
Singapore	Northern Indian	Allen & MacGregor, (1947)	1,478	507	369	482	120
Singapore	Southern Indian	Allen & MacGregor, (1947)	389	124	104	134	27
Singapore	Eurasian	Allen & MacGregor, (1947)	209	100	62	42	5

In 1947, Allen and MacGregor published their findings of the ABO frequencies among blood donors of the Emergency Blood Transfusion Service they organized in Singapore in 1941. Their series included 1,963 Malays, 624 Chinese, 1,478 Northern Indians, 389 Southern Indians and 209 Eurasians. Schebesta in 1952 published his findings on 44 Malays in Perak and Gibson-Hill in 1952 supplied the samples to Mourant who worked out the frequencies of Malays in Singapore on another small sample of 42 cases. In 1950 Simmons et al determined the frequency of 250 Southern Chinese and in 1960 Yeoh gave the frequency based on a sample of 1,000 Chinese blood donors in Singapore.

Thus the available data on the four major locally domiciled races in Malaya and Singapore is limited. This data is tabulated in Table II.

Samples of the principal groups of aboriginal peoples of Malaya — the Negritos, Senois and Aboriginal Malays — have been studied in some detail with regard to ABO frequencies by Green (1949, 1952), Shebesta (1952), Polunin (1953) and Polunin and Sneath (1953). Their findings are summarized in Table III.

REASON FOR THE PRESENT STUDY

The reason for the present study is twofold.

The first is to establish as accurately as possible the normal ABO frequencies among Malays, Chinese, Indians, and Eurasians of Singapore. This will have some anthropological value. The samples of Allen and MacGregor (1947) and of Yeoh (1960) were only of moderate size, especially in the cases of Eurasians and Indians who are made up of many different ethnic groups in themselves. For this reason a larger sample is desirable.

The second reason is that once the ABO frequencies of a sample of normal healthy people are established it is then possible to look into the possible associations of various diseases to blood groups in the different races living here.

MATERIAL AND METHODS

The records of the Singapore Blood Transfusion Service, General Hospital, Singapore were examined and all blood donors with the exceptions mentioned below, registered between the inception of the Service in 1947 and 31st August, 1961 have been taken as the sample in the present series. These donors may be regarded as normal adults for reasons given below.

As the antenatal patients in Kandang Kerbau Hospital are not routinely grouped and as we do not have any large institutional bodies of people which have been blood grouped, such normal adults are not available for use as samples to cross check the frequencies determined by the donor sample.

ACCEPTANCE OF DONORS

The decision to accept a person as a blood donor in the Blood Transfusion Service rests on the following criteria (Gibson-Hill, 1961):—

(1) Haemoglobin of over 85% reckoned by the copper sulphate solution (S.G. 1.052) method (Though this is an approximate method of estimation, it is within acceptable limits).
(2) Age, between 18 and 65.
(3) Weight, above 100 lbs.
(4) Absence of cardiovascular, respiratory or other overt systemic diseases.
(5) Absence of the following past illnesses: infective hepatitis, malaria, filariasis and tuberculosis.

Thus, donors can be regarded as normal healthy adults though the presence of mental, occult and certain chronic diseases cannot be excluded.

CRITERIA FOR ETHNIC DIVISION

The ethnic groups chosen for study are the four major "locally domiciled" ethnic groups, i.e. the Malays, Chinese, Indians and Eurasians.

The criteria for ethnic subdivisions adopted in the present survey of blood donors are as follows:—

(1) *Malays*: All Malays of Federation or Singapore origin, but excluding Indonesians, "Javanese", Boyanese, Sumatrans and Chinese with Malay (Muslim) names.

TABLE III. PUBLISHED DATA ON ABO FREQUENCIES OF MALAYAN ABORIGINAL POPULATIONS UP TO 1961 (AFTER POLUNIN AND SNEATH, 1953).

Place	Population (or Tribe)	No.	O	A	B	AB
North Perak	Lanoh	191	111	54	26	0
North Perak	Tahai	165	115	23	22	5
Kedah	Kensiu	33	11	10	8	4
Kedah	Kenta Nakil	50	31	8	9	2
Kedah	Kinta Bong	54	22	11	19	2
	Total Negritos	493	290	106	84	13
	Percentages		58.8	21.5	17.0	2.6
Ulu Telai	Semai	135	76	2	53	4
West of Main Watershed	Semai	101	40	12	44	5
Sungei Plus	Temer	104	50	7	47	0
Grik	Temer	18	11	6	1	0
Tapah-Cameron Highlands	Semai	117	62	12	36	7
	Total Senoi	475	239	39	181	16
	Percentages		50.3	8.2	38.1	3.4
Kuala Redang & Sungei Lebam	Orang Laut Seletar	44	12	0	31	1
Ulu Langat	Orang Dalam	31	17	11	2	1
Bukit Lanjan	Orang Darat	46	31	5	8	2
Lenek & Sungei Lenggiu	Orang Ulu	59	27	16	14	2
Selangor	Various	66	31	12	19	4
	Total Aboriginal Malays	246	118	44	74	10
	Percentages		48.0	17.9	30.1	4.0

(2) *Chinese*: All Chinese from any part of China including Chinese Muslim converts (It was observed that the vast majority are Southern Chinese).
(3) *Indians*: Northern and Southern Indians, Pakistanis and Ceylonese are included under Indians but Anglo-Indians, Burghers, Gurkhas and Goans with Portuguese names are excluded.
(4) *Eurasians* include Anglo-Indians, Burghers and Goans with Portuguese surnames.

Any donor not coming under the above ethnic groups or within the above criteria was discarded from the sample. This excluded all donors of other Asian and Caucasoid origins (It was noticed during the "count" that European caucasoids form a very large proportion of the total donors and that this high proportion was only reduced in recent years).

The four ethnic groups in themselves are made up of mixed peoples. The vast majority of Chinese come from the three southern provinces of Fukien, Kwangtung and Kwangsi and are further subdivided into half a dozen main dialectal groups. There is a sprinkling of northern Chinese, most of whom are Shanghainese.

The Malays are of heterogeneous origin also, many having come from the Federation of Malaya and Indonesia. The Singapore Police Force has a considerable number of Malays from the Federation in its service and the Police Force is one of the major sources of Malay donors here.

The heterogeneity of the "Indian and Pakistani" and Eurasian groups is obvious.

METHOD USED IN DETERMINATION OF BLOOD GROUP

The donor cells are tested against Anti-A and Anti-B sera and cross checked by testing the serum against A-cells and B-cells. Agglutination is observed in precipitin tubes and if there is any doubt, a drop is placed on a slide and examined under a microscope.

RESULTS

In all a total of 27,052 blood donors were available for analysis, comprising 15,262 Chinese, 5,461 Malays, 5,000 Indians and 1,329 Eurasians. The results of the present investigation are summarized in Table IV, which gives the absolute numbers in each ethnic and blood group and the corresponding percentages.

The ethnic distribution of the donor sample is compared to the ethnic distribution of the general population in Singapore in Table V. From it, it will be seen that though the Chinese form the largest group of donors, 56.42%, it is not proportionate to its populat on distribution as 79.82% (adjusted; see Table V) of Singapore's population is Chinese. It is the only ethnic group

TABLE IV. THE ABO FREQUENCIES OF 27,052 BLOOD DONORS AMONG THE FOUR MAJOR LOCALLY DOMICILED ETHNIC GROUPS.

Ethnic Group	Total No. of cases	Absolute Numbers				Percentages			
		O	A	B	AB	O	A	B	AB
Chinese	15,262	6,664	3.967	3,814	837	43.53	25.99	24.99	5.48
Malays	5.461	2,098	1,369	1,596	398	38.42	25.07	29.23	7.29
Indians	5.000	1.951	1,051	1,680	318	39.02	21.02	33.60	6.36
Eurasians	1,329	609	329	311	80	45.82	24.76	23.40	6.02

TABLE V

DISTRIBUTION OF DONOR SAMPLE AND GENERAL POPULATION IN SINGAPORE AMONG THE FOUR MAJOR LOCALLY DOMICILED ETHNIC GROUPS (ADJUSTED TO THE CRITERIA FOR ETHNIC DIVISION ADOPTED IN THIS STUDY)

Ethnic Group	General Population *		Donor Sample	
	Number	Percentage	Number	Percentage
Chinese	1,090,595	79.77	15,262	56.42
Malays	135,663	9.92	5,461	20.19
Indians	129,510	9.48	5,000	18.48
Eurasians	11,382	0.83	1,329	4.91

* From the 1957 Census, Department of Statistics, 1959.

whose donor percentage is lower than its percentage distribution in the general population.

CALCULATION OF GENE FREQUENCIES

In 1908 Epstein and Ottenberg suggested that the ABO blood groups were inherited and this was proved two years later by von Dungern and Hirszfeld (1910). The exact method of inheritance was worked out by a mathematician Bernstein in 1924 when he showed that the four groups were inherited as Mendelian characters by means of three allelic genes A, B and O. The Bernstein theory was extended in 1930 by Thomsen, Friedenreich and Worsaae to include the subgroups A_1 and A_2 by postulating the four allele theory of inheritance and this was shown to be valid a year later by Friedenreich and Zacho (1931).

An offspring can receive from each parent one of four allelic genes A_1, A_2, B or O, with ten possible combinations, thus giving rise to ten genotypes. As some genotypes are indistinguishable from the others, (unless special data of other members of a family are available), there are only six phenotypes. This is presented in tabulated form in Table VII.

TABLE VII

THE A_1 B_2 BO GROUPS AS DEFINED BY ANTI-A, ANTI-B AND ALPHA$_1$

(AFTER RACE AND SANGER, 1958)

Genotypes		Phenotypes
A_1 A_1		
A_1 A_2	A_1	
A_1 O		A
A_2 A_2		
A_2 O	A_2	
B B		
B O	B	
A_1 B	A_1 B	AB
A_2 B	A_2 B	
O O	O	

From the absolute values of the group O, A and B, the gene frequencies p, q and r representing the A, B and O genes can be calculated. The gene frequencies (p_1 and p_2) of the sub-groups A_1 and A_2 were not calculated separately. Moreover, it has been shown that many South-East Asian populations have no A_2 in the samples tested (Simmons and Graydon, 1951; Graydon et al, 1952; Polunin and Sneath, 1953). A_2 is also absent in samples of Chinese in South China (Simmons et al, 1950), and among Chinese sampled in New York City (Wiener et al, 1944; Miller et al, 1950 and 1951; Sussman, 1956).

Bernstein (1924) devised the following formula for calculating the gene frequencies from the ABO frequencies:—

$$p = 1 - \sqrt{\bar{O} + \bar{A}},$$

$$q = 1 - \sqrt{\bar{O} + \bar{B}},$$

$$r = \sqrt{\bar{O}}.$$

Where p = frequency of A gene,
q = frequency of B gene,
and r = frequency of O gene,
and $\bar{A}$, $\bar{B}$ and $\bar{O}$ are the proportions of the respective blood groups in the sample.

In practice, p + q + r did not add up to exactly 1, and he subsequently improved his formula by taking into account this deviation from unity in his calculations. The method was further refined by Stevens in 1938. Fisher then applied his maximum likelihood method to the problem and his formulae were used and published by Dobson and Ikin in 1946 and Frazer Roberts in 1948.

Fisher's method is probably the more accurate and his formulae are used in the gene frequency calculation here and are given below:—

$$p = \frac{t-s}{v},\quad q = \frac{u-s}{v}\quad \text{and} \quad r = \frac{s}{v},$$

Where $s = \sqrt{O}$,

$$t = \sqrt{O + A},$$

$$u = \sqrt{O + B},$$

and $v = t + u - s$,

in which O, A and B are the actual number of cases in Groups O, A and B in the sample.

Applying these formulae the gene frequencies for the four ethnic groups investigated are given in Table VIII below.

As the frequencies of the A and B genes are known, it is possible to calculate the expected number of AB bloods in the sample. The significance of the deviation, i.e. the difference between the expected number of AB and the observed number of AB, can then be determined by applying the chi-square method as follows:

If $w = v^2$

x = Expected number of AB

$= w - (O + A + B)$

y = Observed number of AB

z = Deviation $= x - y$

Then variance $= \dfrac{wx}{tu.}$

$$\chi^2 = \frac{(\text{Deviation})^2}{\text{Variance}} = \frac{tuz^2}{wx}, \quad \text{for one degree of freedom}$$

The probability P, can then be obtained from Fisher's Table of χ^2 (Fisher, 1925) and is given in the last column of Table VII above.

It will be seen that in no ethnic group does P approach 0.05, the 5% level of significance. That is, the observed number of group AB does not vary significantly from the number of group AB calculated on the far larger observed numbers in groups A, B and O.

DISCUSSION

Sources of Error and Bias

To determine the ABO frequency distribution of any population, ideally the whole population should be studied; alternatively, a perfect random sample should be used. As both these alternatives are theoretical, except in very small populations, one can only be content with securing as large and as representative a sample as possible for analysis.

(a) *Ethnic Grouping.* The Chinese group is fairly well defined. It is possible that some of the Malasians other than Malays, e.g. Javanese, Boyanese, etc., preferred to be registered as Malays in the Singapore Blood Transfusion Service and have therefore been included in the Malay group in this study. Similar errors may have crept into the Indian-Pakistani-Ceylonese and Eurasian groups. As the total numbers studied are large and any doubtful "case" is rejected from the series, this source of error is negligible.

(b) *Subgroups within the Major Ethnic Groups.* This subject is very complex but has to be considered when different series of the same ethnic groups are compared. There are ten dialectal groups listed in the 1957 Census among Chinese in Singapore namely, Hokkien, Teochew, Cantonese, Hiananese, Hakka (Khek), Foochow (Hockchiu), Shanghainese, Henhua, Hokchia and Kwongsai; in addition there is a group of "other Chinese" representing less than 0.012% of the total Chinese. With the exception of the Shanghainese (just over 1% of the total) all are southern Chinese. Variations in ABO distribution within the southern Chinese provinces are small (Mourant, 1954) and are not significant.

There are three major Malaysian groups resident in Singapore, namely the Malays, Javanese and Boyanese and three minor groups (0.4%) — the Bugis, Bajarese and Menangkabau. The frequencies of the Malaysian subgroups are again essentially similar (Mourant, 1954) and in this study, effort has been made to include only Malays in the analysis.

There are slight but significant differences in the ABO distribution between Northern and Southern Indians (Mourant, 1954). Northern Indians represent about 12% of the total Indian population of Singapore. In the present series,

TABLE VIII. GENE FREQUENCIES OF THE FOUR MAJOR LOCALLY DOMICILED ETHNIC GROUPS.

Ethnic Group	p	q	r	χ^2	P (df = 1)*
Chinese	0.17371	0.16769	0.65860	2.362	> 0.1, < 0.2
Malays	0.17707	0.20275	0.62018	0.067	> 0.7, < 0.8
Indians	0.14984	0.22698	0.62318	1.082	> 0.2, < 0.3
Eurasians	0.16397	0.15583	0.68020	1.702	> 0.1, < 0.2

* Fisher, 1925

the proportion of Northern to Southern Indians is unknown owing to incomplete data though there is reason to believe that the great majority (about 80%) of the blood donors studied in the Indian group are Southern Indians. Therefore there is some doubt as to the validity of comparing the present series with others.

(c) *Surnames.* It has been shown in European countries that people of certain surnames tend to have a frequency distribution peculiar to themselves and distinct from that of the general population (Mourant, 1954). This appears to be an effect of ethnic grouping as surnames are peculiar to certain European ethnic groups — e.g. the Welsh, Irish, etc., have distinctive surnames and are in themselves distinctive population groups. There appears to be no study on this aspect of blood group distribution among the Chinese, Malays or Indians. The Chinese marriage custom precludes marriages between people of the same surname except in rare instances, and this will favour homogeneity especially when this custom has been observed for centuries. All the Malays and most of the Indians domiciled in Singapore do not have surnames in their name systems and any association with surnames in these peoples will be extremely difficult if not impossible to evaluate. Some of the Indian ethnic subgroups are identified by surnames peculiar to them and like the European examples will presumably have a distinctive distribution.

(d) *Disease.* There is a known relationship between blood groups and certain diseases. In the selection of blood donors as given above, the diseases that are known to have such associations would have been effectively excluded.

(e) *Year to Year Variation.* It was noted that there were slight variations in the distribution within each ethnic group from year to year. Apart from the various factors discussed above these variations could be due to mere chance as in no instance was the deviation statistically significant.

The results of the present investigations are summarized in Table V, which gives the absolute number of cases in each ethnic and blood group and the corresponding percentages.

From the Table it will be seen that the four ethnic groups, as expected, have different frequency distributions. The Chinese have a relatively high blood group O frequency like the European Caucasoids, and as high a B frequency as A, which is charisteristic among Southern Chinese (further discussed below), but differs from the European frequency where A is always much higher than B.

The chief feature in the distribution of the Malays is that group B is higher than group A by about 4%. But it is among the Indians that the group B frequency is really high being 33.6% against group A of only 21%, a difference of over 12%. This is characteristic of the races living on the Indian sub-continent, excepting the peoples on the Himalayan foothills and the Burmese border.

The Eurasian frequencies resemble those of the Singapore Chinese rather than those of the Europeans and will be further commented on below.

Chinese ABO Frequency Distributions.

The ABO frequencies of Chinese in Singapore found in the present study are compared with the frequencies found by Allen and MacGregor (1947), Simmons et al (1950) and Yeoh (1960) and with other overseas Chinese and Chinese in China in Table X.

The frequencies of the four Malayan (Singapore and Federation) series are generally similar. Groups O and A frequencies are practically identical. Group B frequencies range from 20.8% to 27.7%. This range though wide is less than twice standard deviation. The differences in group AB are proportionately greater, ranging from 3.13% to 7.6%. To determine the significance of these differences the AB frequencies of Allen and MacGregor, Simmons et al and Yeoh are tested against those of the present series by calculating χ^2 using the "Fourfold" Table method (Bradford Hill, 1961) as follows:

$$\chi^2 = \frac{(ad - bc)^2\ (a + b + c + d)}{(a + b)\ (c + d)\ (a + c)\ (b + d)},$$

where a = the observed number in Blood Groups O, A and B,

and b = the observed number in Blood Group AB,

in one series and c and d the corresponding numbers in the other series.

The values for chi-square and P, where n = 1, are given in Table IX.

TABLE IX

Series of	χ^2	P
Allen and MacGregor.	0.1461	> 0.7
Simmons et al.	0.0211	> 0.8
Yeoh.	5.4440	≏ 0.02

It will be seen that that in the first two series P is greater than 0.02 and hence do not reach the 5% level of significance; in Yeoh's series the 5% level is just reached, but the significance is probably doubtful.

Allen and MacGregor's sample is a heterogeneous one of Singapore Chinese as in the present series. Simmons et al selected 250 southern Chinese of known dialectal group, comprising 100 Hakkas, 97 Cantonese, 44 Hokkiens and 9 Hainanese, but they did not state whether this was a random selection or not. Yeoh's sample of 1000 were mainly with surnames of Lim (林), Tan (陳) and Goh (吳), (Yeoh, 1961). It is quite possible that there are differences in frequency distribution related to surnames among Chinese and this is worthwhile investigating further (See above).

The only other published sample of overseas Chinese in South-East Asia, that of Bais and Verhoef (1924), sampled among Chinese labourers in Sumatra, has a distribution closely following that of Singapore Chinese.

The Table also shows the similarity of the frequencies of overseas Chinese to those of Southern Chinese, i.e. Chinese sampled in Kwangtung, Fukien and Taiwan (Table X, Series 6-11).

As one proceeds northwards, the frequencies change. Group O, which is over 40% in the south falls to around 30% in the Hwang Ho Valley (Yang, 1929), Shantung Province (Yang. 1928) and Peking (Huie, 1928), while the B frequency rises from around 26% to around 30%. This becomes even more marked in the North-Eastern city of Shenyang (Moukden) (Mori, 1931) where the B frequency is 33%, higher than O, which is only 32% (Table X, Series 13-16). The Overseas Chinese sampled in New York by Levine and Wong (1943) have a distribution closer to that of Northern Chinese (Table IX, Series 12).

The Manchus (Fukumachi, 1923) and pure Mongols (Jettmar, 1930) (Table X, Series 17 and 18) have an even higher B incidence and lower O than those of Northern Chinese as can be seen in the Table.

Malay **ABO Frequency Distributions.**

The Malay ABO frequencies are compared with those of Schebesta (1952), Mourant (1953), and Allen and MacGregor (1947) in Table XI. The samples of Schebesta and Mourant are too small to permit a satisfactory evaluation. The present series have a distribution very similar to that of Allen and MacGregor except that group B is rather higher in the present series, 29.23% against 25.67%.

Indonesians sampled in Djakarta by Sutarman (1951), and pure Menangkabaus sampled in Middle Sumatra by Eithoven-Schuil (1931), also show a higher B incidence than A (Table XI, Series 5 and 6).

Indian ABO Frequency Distributions.

The ABO frequencies of Indians in Singapore are compared with those sampled by Allen and MacGregor (1947), Indians in India, Sinhalese and Tamils in Ceylon in Table XII.

Allen and MacGregor divided Indians into "Northern Indians" and "Southern Indians", but unfortunately the criteria for this sub-division have not been given and comparison is therefore difficult.

No sub-division of Indians, Pakistanis and Ceylonese has been attempted in the present series owing to incomplete data. All these subjects have been grouped together in the hope that it will be a fair representation of the "local mixture" of the great variety of ethnic groups and sub-groups that have migrated here from the Indian sub-continent.

The largest published series of ABO frequencies of "Northern Indians" — Bombay (Desai, 1955) and Sikhs of Punjab (House and Mahanolobis, 1939-45) and "Southern Indians" — Tamils (Naidu and Nathan, 1938) and Malayalees (Ayer and Mummurthi, 1953) and Ceylonese Sinhalese (Seneviratne, 1944) and Tamils (Green, 1929) are included in Table XII for comparison.

Owing to the enormous ethnic complexities of the Indian sub-continent it is beyond the scope of the writer to make any comments apart from the generalizations made in the earlier part of the discussion.

Eurasian ABO Frequency Distributions.

The Singapore Eurasian frequencies based on a large sample bave been established for the first time. The ABO frequencies of Singapore Eurasians are compared with those of Eurasians in Ceylon and India in Table XIII.

It can be seen from Table XIII that the present series has frequencies which show some differences from those previously published. The latter series has a much higher A than B; in the present series they are about equal. Group

TABLE X.* The ABO and Gene Frequencies of Chinese in Singapore and Malaya Compared with other Overseas Chinese and Chinese in China.

Series	Place	Population	Authors	Percentages					p	q	r
				Number	O	A	B	AB			
1.	Singapore	"Overseas Chinese"	Present Series, 1961	15,262	43.53	25.99	24.99	5.48	17.363	16.741	65.896
2.	Singapore	"Overseas Chinese"	Allen & MacGregor, 1947	624	43.11	24.04	27.72	3.13	15.87	18.09	66.04
3.	Malaya	"South Chinese"	Simmons et al, 1950	250	46.4	25.2	20.8	7.6	16.5	13.9	68.1
4.	Singapore	"Overseas Chinese"	Yeoh, 1960	1,000	44.30	25.50	26.50	3.70	16.79	17.39	65.82
5.	Sumatra, East Coast	Chinese (Imported labour)	Bais & Werhoef, 1924	592	40.20	25.00	27.53	7.26	17.67	19.22	63.11
6.	Taiwan	Hokkiens	Haebara, 1938	3,885	42.19	28.91	22.83	6.07	19.36	15.68	64.96
7.	Hainan, Haikow	Hainanese	Yokio & Kawabe, 1940	601	38.4	27.8	27.1	5.7	—	—	—
8.	Taiwan	Hakka from Kwangtung Province	Tsai & Sheen, 1954	1,186	41.3	27.8	25.8	5.1	18.2	16.9	64.9
9.	Kwangtung, Canton	Cantonese	Dormanns, 1929	992	45.87	22.78	25.20	6.15	15.66	17.09	67.25
10.	Taiwan	Chinese	Wang et al, 1955	4,745	43.62	27.12	23.69	5.56	17.97	15.90	66.13
11.	Taiwan	Fukien, Kwangsi, & Kwangtung	Wang et al, 1955	3,864	34.70	29.87	26.86	8.57	21.53	19.63	58.84
12.	U.S.A., New York City	"Overseas Chinese"	Levine & Wong, 1943	150	30.00	34.00	25.33	10.67	25.57	19.96	54.47
13.	Course of Hwang Ho	Chinese	Yang, 1929	2,127	34.2	30.8	27.7	7.3	21.4	19.1	59.1
14.	Shantung	Chinese	Yang, 1928	1,361	34.9	30.4	27.8	6.8	20.9	19.3	59.8
15.	Peking	Chinese	Huie, 1928	1,296	28.6	26.6	32.0	12.8	22.0	25.5	52.5
16.	Moukden	Chinese	Mori, 1931	655	31.91	26.26	33.13	8.70	19.39	23.78	56.83
17.	Moukden	Manchu	Fukamachi, 1923	199	26.63	26.63	38.19	8.54	19.67	27.27	53.06
18.	Mongolia, Ulan Bator	Pure Mongols	Jettmar, 1930	114	28.6	23.2	31.3	16.9	—	—	—

* After Mourant et al in The ABO Blood Groups. So are Tables XI, XII and XIII.

TABLE XI. The ABO and Gene Frequencies of Malays Compared with Those of Indonesians and Menangkabaus.

Series	Place	Population	Authors	Number	Percentages				p	q	r
					O	A	B	AB			
1.	Singapore	Malays (Donors)	Present Series, 1961	5,461	38.42	25.07	29.23	7.29	17.70	20.26	62.04
2.	Perak	Malays	Schebesta, 1952	44	30.09	20.45	43.18	2.27	*	*	*
3.	Singapore	Malays	Gibson-Hill, 1953	42	40.48	16.67	40.48	2.38	*	*	*
4.	Singapore	Malays (Donors)	Allen & MacGregor, 1947	1,963	40.45	26.54	25.67	7.34	18.65	18.11	63.24
5.	Djakarta	Indonesians (soldiers)	Sutarman, 1951	7,129	39.21	26.75	27.32	6.72	18.44	18.80	62.72
6.	Middle Sumatra	Manangkabaus (pure)	Eithoven-Schuil, 1931	461	34.49	27.11	31.89	6.51	18.64	21.64	59.72

* Sample too small.

TABLE XII. The ABO and Gene Frequencies of "Indians" in Singapore Compared with Northern and Southern Indians and Sinhalese and Tamils in Ceylon.

Series	Place	Population	Authors	Number	Percentages				p	q	r
					O	A	B	AB			
1.	Singapore	Indians, Pakistanis & Ceylonese	Present Series, 1961	5,000	39.02	21.02	33.60	6.36	14.983	22.700	62.317
2.	Singapore	Northern Indians	Allen & MacGregor, 1947	1,478	34.30	24.97	32.61	8.12	18.22	23.04	58.74
3.	Singapore	Southern Indians	Allen & MacGregor, 1947	389	31.88	26.73	34.45	6.94	18.70	23.62	57.68
4.	Bombay, Ahmadabad	Donors	Desai, 1955	2,668	32.61	21.70	36.39	9.30	16.90	26.26	56.84
5.	Punjab	Sikhs (Soldiers)	House & Mahalanobis, 1939-45	2,278	35.34	25.24	30.60	8.82	18.76	22.12	59.12
6.	Madras	Tamil (mixed religions)	Naidu & Nathan	1,740	43.1	24.0	29.4	3.5	15.0	18.2	66.8
7.	Malabar, Wynad	Malayalam speakers	Ayer & Mummurthi, 1953	177	44.07	20.34	31.07	4.52	13.36	19.79	66.85
8.	Colombo	Sinhalese	Seneviratne, 1944	3,606	46.42	22.82	26.51	4.24	14.64	16.83	68.53
9.	Born in Ceylon	Tamils	Greene, 1929	2,000	39.65	19.55	33.55	7.25	14.41	23.01	65.58

TABLE XIII. The ABO and Gene Frequencies of Singapore Eurasians Compared with Eurasians in Ceylon and India.

Series	Place	Population	Authors	Number	Percentages				p	q	r
					O	A	B	AB			
1.	Singapore	Eurasians (Donors)	Present Series, 1961	1,329	45.82	24.76	23.40	6.02	16.40	15.58	68.02
2.	Singapore	Eurasians (Donors)	Allen & MacGregor, 1947	209	47.85	29.66	20.09	2.39	17.68	12.04	70.28
3.	Colombo	Burghers	Seneviratne, 1944	294	46.60	28.57	19.73	5.10	18.55	13.29	68.16
4.	Calcutta	Anglo-Indians	Macfarlane, 1942	210	42.38	29.52	22.86	5.24	19.27	15.25	64.48
5.	Malabar, Wynad	Anglo-Indians	Ayer & Mummurthi, 1953	153	43.14	23.53	21.57	11.76	19.21	18.02	62.77

AB is more than twice as high in the present series. Apart from sampling factors, these differences may be due to different criteria being adopted for the definition of an "Eurasian" in the two series.

In both samples, group O has a frequency of around 45% and group A is always higher than group B in contrast to Indians and Ceylonese in whom, as has been noted above, group B is always commoner than group A.

Singapore Eurasian frequencies run closely parallel to those of Anglo-Indians (Macfarlane, 1942; Ayer and Mummurthi, 1953) and Burghers (Seneviratne, 1944) sampled in India and Ceylon and suggest that most of our Eurasians are of Indo-European descent. This is also borne out by the observation during the count of Eurasian blood donors that most of their surnames are of Portuguese, British and Dutch origins.

SUMMARY

1. A brief review is made of the ABO blood group system.
2. The published data on the ABO frequencies for populations in Malaya and Singapore is surveyed. Apart from the aboriginal populations no detailed study has been made on ABO frequencies in Singapore and Malaya.
3. 27,052 blood donors of the Singapore Blood Transfusion Service have been studied to determine the normal ABO frequencies. This includes 15,262 Chinese, 5,461 Malay, 5,000 Indian and 1,329 Eurasian donors. The result are summarized in Table IV.
4. The gene frequencies for the four ethnic groups were calculated. The results are given in Table VIII.
5. The sources of error and bias of the present series and the validity of comparing it with other series are discussed.
6. The ABO frequencies of Overseas Chinese in Singapore are compared with those of Chinese elsewhere. The ABO frequencies of Malays are essentially similar to those of Indonesians sampled in Djakarta and Sumatra (pure Menangkabaus). The ABO frequencies of Indians in Singapore are compared with those of Indians in India. The ABO frequencies of Eurasians in Singapore have been established in a moderately large sample, and are compared with those of Eurasian populations in India and Ceylon. These data are summarized in Tables IX to XII.

ACKNOWLEDGEMENTS

I am grateful to Professor G. S. Yeoh for encouragement; to Dr. Ivan Polunin for helpful criticism during the preparation of the paper and to Dr. M. M. H. Gibson-Hill, Medical Officer-in-Charge, Blood Transfusion Service, General Hospital, Singapore for supplying technical data pertaining to the Service. My thanks are also due to those medical students who helped in the collection of the data and to Miss K. L. Fam for typing the script.

REFERENCES

Aird, I., Bentall, H.H., and Roberts, J.A.F. (1953): Relationship between cancer of the stomach and the ABO groups. B.M.J., i, 799-801.

Allen, G.V. and Scott, R.G.S. (1947): The emergency blood transfusion in Singapore. Med. J. Malaya, 2, 136-147.

Allen, F.H., Diamond, L.K. and Niedziela, B. (1951): A new blood group antigen. Nature, 167, 482.

Ayer, A.A. and Mummurthi, C. (1953): J. Anat. Sec. India, 2, 6-12, and personal communication (1957) to Mourant et al (1958) in The ABO Blood Groups. Oxford, Blackwell Scientific Publications, p 131.

Bais, W.J. and Verhoef, A.W. (1924): Biochemical Index of various races in the East Indian Archipelago. J. Immunol., 9, 383-386.

Bernstein, F. (1924): Ergebnisse einer biostatischen zusammenfassenden Betrachtung uber die Erblischen blutsruktuien des Menschen. Klin. Wschr., 3, 1495-1497.

Boyns, D.R. Quoted by Polunin (1953) in The medical natural history of Malayan aborigines. Med. J. Malaya, 8, 87.

Bradford-Hill, A. (1961): Principles of Medical Statistics. 7th Ed., p 172. London, Lancet Ltd.

Callender, S.T., and Race, R.R. (1946): A serological and genetical study of multiple antibodies formed in response to blood transfusion by a patient with lupus erythematosus diffusus. Ann. Eugen. Lond., 13, 102-117.

Callender, S.T., Race, R.R. and Paykoc, Z.V. (1945): Hypersensitivity to transfused blood. B.M.J., ii, 83.

Census (1957), Department of Statistics, Singapore, 1959.

Coombs, R.R.A., Mourant, A.E., and Race, R.R. (1946). In vivo isosensitization of red cells in babies with haemolytic disease. Lancet, i, 264-266.

Cutbush, M., Mollison, P.L. and Parkin, D.M. (1950): A new human blood group. Nature, 165, 188.

Desai, M.D. (1955): Quoted by Mourant et al (1958) in the ABO Blood Groups, p 126.

Dobson, Aileen, M. and Ikin, Elizabeth, W. (1946): The ABO blood groups in the United Kingdom; frequencies based on a very large sample. J. Path. Bact., 48, 221-227.

Dormanns, E.A. (1929): Blutgruppenstudien in Kanton (China). Munch. med. Wschr., 76, 1467.

Dungern, E. von, and Hirszfeld, L. (1910): Ueber Vererbung gruppenspezifischer Strukturen des Blutes, II. Z. Immun. Forsch., 6, 248-292.

Eithoven-Schuil, A. (1931): Blood groups in Dutch East India. Geneesk. Tijdschr. v. Nederl. Indie, 71, 728-731.

Epstein, A.A. and Ottenberg, R. (1908): Simple method of performing serum reactions. Proc. N.Y. path. Soc., 8, 117-123.

Fisher, Sir Ronald, A. (1925): Statistical Methods for Research Workers, 1925 — 13th Ed., 1958. Edinburgh, Oliver and Boyd Ltd.

Friedenreich, V. and Zacho, A. (1931): Die Differentialdiagnose zwischen den 'Untergruppen A_1 and A_2'. Z. Rassenphysiol, 4, 164-191.

Fukamachi, H. (1923): Biochemical race-index of Koreans, Manchus and Japanese. J. Immunol., 8, 291-294.

Graydon, J.J., Simmons, R.T., Semple, N.M., Clapham, L.J. and Wallace, E.H. (1952): Blood genetics of various populations in Borneo. Med. J. Aust., i, 694-702.

Green, R. (1949): Anthropological Blood Groups among the Sakai. Bull. Raffles Mus., B, No. 4, 130-132.

Green, R. (1929): Relation of blood groups to immunity from malaria and to gametocyte formation. Tr. Roy. Soc. Trop. Med. & Hyg., 23, 161-166.

Gibson-Hill, M.M.H. (1953): Personal communication to Mourant et al (1958) in The ABO Blood Groups, p. 137.

Gibson-Hill, M.M.H. (1961): Personal communication.

Haebara, C. (1938): Studies on blood types M and N; distribution of M, N and O, A and B blood types in various racial tribes resident in Formosa. J. med. Ass. Formosa, 37, 579.

Hirszfeld, L., and Hirszfeld, Hanna. (1918-1919): Essai d'application des methodes serologiques au probleme des races. Anthropologie, 29, 505-537.

House, R.J. and Mahanalobis, P.C. (1939): Personal communication to Mourant et al (1958) in The ABO Blood Groups, p. 117.

Huie. (1928) Quoted by Jettmar (1930) in Blutgruppenuntersuchungen in der Nordostmongolei und der Nordmandchurei. Mitt. d. anthrop. Ges., Wien. 60, 39-47.

Jettmar, H.M. (1930): Blutgruppenuntersuchungen in der Nordostmongolei und der Nordmandschurei. Mitt, anthrop. Ges., Wien, 60, 39-47.

Kobayasi, K. (1941). Quoted by Mourant et al (1958) in The ABO Blood Groups, p. 147.

Landsteiner, K. (1900): Zur Kenntnis der Antifermentativen, lytischen und agglutinierenden Wirkungen des Blutserums und der Lymphe. Zbl. Bakt., 27, 357-362.

Landsteiner, K. (1901): Agglutinationserscheinungen normalen menschlichen Blutes. Wien. Klin. Wschr., 14, 1132-1134.

Landsteiner, K. and Levine, P. (1927): A new agglutinable factor differentiating individual human bloods. Proc. Soc. exp. Biol. N.Y., 24. 600-602.

Landsteiner, K. and Levine, P. (1927): Further observations on individual differences of human blood. Proc. Soc. exp. Biol., N.Y., 24, 941-942.

Landsteiner, K. and Wiener, A.S. (1940): An agglutinable factor in human blood recognised by immune sera for rhesus blood. Proc. Soc. exp. Biol., N.Y., 43, 223.

Levine, P. and Wong, Helena (1943): Incidence of Rh factor and erythroblastosis foetalis in Chinese. Amer. J. Obstet. Gynec., 45, 832-835.

MacFarlane, Eileen W.E. (1942): Blood groups of Eurasians and Parsees in Calcutta. Amer. Nat., 76, 520-525.

Miller, E.B., Tanner, H.D. and Hsu, Ching-Feng (1950): The P factor and its variants in Caucasians, Negroes and Chinese. J. Lab. clin. med.. 36, 230-233.

Miller, E.B., Rosenfield, R.E. and Vogel, P. (1951): The incidence of some of the new blood agglutinogens in Chinese and Negroes. Amer. J. phys. Anthrop., 9, 115-126.

Mori, S. (1931) Quoted by Mourant et al (1958) in The ABO Blood Groups, p. 149.

Mourant, A.E. (1954): The Distribution of the Human Blood Groups. Oxford, Blackwell Scientific Publications.

Mourant, A.E., Kopec, A.C. and Domaniewska-Sobczak, K. (1958): The ABO Blood Groups. Comprehensive Tables and Maps of World Distribution. Oxford, Blackwell Scientific Publications.

Naidu and Nathan (1938) Quoted by MacFarlane (1938) in Blood group distribution in India with special reference to Bengal. J. Genet., 36. 225-237.

Polunin, I. (1953): The medical natural history of Malayan Aborigines. Med. J. Malaya. 8, 55-175.

Polunin, I. and Sneath, P.H.A. (1953): Studies of blood groups in South-East Asia. J.R. anthrop. Inst., 83, 215-255.

Race. R.R. and Sanger. Ruth. (1958): Blood Groups in Man. 3rd Ed., Oxford, Blackwell Scientific Publications.

Roberts, J.A.F. (1948): The frequencies of the ABO blood groups in South-Western England. Ann. Eugen., Lond., 14, 109-116.

Schebesta, P. (1952): Die Negrito Asiens. Studia Inst. Anthropos., 6, Wien.

Seneviratne, R.D. (1941): Distribution of blood groups in Ceylon. J. Ceylon Br. Brit. med. Ass., 40, 148-151.

Simmons, R.T., Graydon, J.J., Semple, N.M. and Green, R. (1950): The $A_1 - A_2$ - B - O, M - N and Rh blood groups in Southern Chinese: Hak-kas, Cantonese and Hokkas. Med. J. Aust., ii, 917-922.

Simons, R.T. and Graydon, J.J. (1951): A comparison of the blood groups, sub-groups, M - N and Rh types found in Java with those found in other parts of Indonesia, together with a summary of the evidence for north-south gradients in the values for the blood genes q, m and R1. Med. J. Aust., i, 173-179.

Stevens, W.L. (1938): Estimation of blood group genes frequencies. Ann. Eugen., Lond., 8, 362-375.

Sussman, L.N. (1956): Blood groups in Chinese of New York area; studies with A - B - O, M - N, Rh - Hr, Kell and P groups. Amer. J. clin. Path., 26, 471-476.

Sutarman, (1951): Indonesian Red Cross Society Blood transfusion service, a review, Djakarta.

Thomsen, O., Friedenreich, V. and Worsaae, E. (1930): Uber die moglichtkeit der Existenz zweier neuer Blutgruppen; auch ein Beitrag zur Beleuchtung sogennanter Untergruppen. Acta. Path. Microbiol. Scand., 7, 157-190.

Tsai. Hsi Kuei, and Sheen. Nae-Lin. (1954): J. Formosan med. Ass., 53, 83-87. and quoted by Mourant et al, loco citato.

Wang, K.Y., Liu, J.S. and Chu, S.Y. (1955): Selected Papers, Nat. Defence med. Centre, Taipei, Taiwan, 10-13.

Wiener, A.S., Sonn, Eve B. and Yi, C.L. (1944): Blood groups, M - N, and Rh types of Chinese. Amer. J. phys. Anthrop. n.s. 2, 267-273.

Yang. F.M. (1929): Isohaemaglutination examination of Chinese. J. Orient. med., 9, 57-58.

Yang. F.M. (1929): Quoted by Liang Backiang in Munch. med. Wschr.. 76. 1466-1467.

Yeoh, G.S. (1960): Carcinoma of the stomach. Sing. med. J.. 1, 140-147.

Yeoh, G.S. (1961): Personal communication.

Yokio and Kawabe (1940): Quoted by Kobayasi (1941) loco citato.