Random and Nonrandom Inbreeding Revealed from Isonymy Study. I. Small Cities of Japan

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INTRODUCTION

Crow and Mange [1] have shown that isonymous marriages (i.e., between persons of the same surname) may be used for the estimation of the inbreeding coefficient, which in simple cases is one-fourth of the fraction of isonymous marriages. Actually, the parallelism between paternally inherited genetic characters and surnames was first recognized by Darwin [2], who estimated the frequency of first-cousin marriages. Especially in Spanish-speaking countries, where each person uses both paternal and maternal names [3], the surname may be a very useful trait for the study of human population structure [4].

In the present communication, we shall examine surname as a genetic indicator with special reference to inbreeding. A special feature of Japanese material is the coexistence of two systems of name transmission. In a regular patrilineal system, children take the name associated with their father's Y chromosome, while, in matrilineal inheritance, children take the name that would be associated with the maternal W chromosome if the female were heterogametic. Illegitimacy, adoption, and other changes of name are analogous to gene mutation. One aim of this paper is to investigate the relative frequency of changes in surname.

SURNAME IN JAPAN

History. The following information is based on Watanabe [5] and Sakuma [6]. The surname of the typical Japanese person consists of two or three Chinese letters. It is taken originally from places where ancestors settled, from professions, or from the nature of ancestral clans. According to old records, many classes, including farmers, had first and family names. Later on, however, the use of a family name for the common people was prohibited by feudal lords in order to establish a status difference between the governing classes and the masses. It was not until the Meiji revolution that farmers and the other common people joined the noble and military classes in having surnames (cabinet decree no. 22 in 1875). Some new names were created at that time, but usually names already in use by the nobility were taken.

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On some occasions a certain surname was given to all persons who lived in a small hamlet. This and similar practices would cause an upward bias in the estimate of the inbreeding coefficient. Despite such effects, the establishment of the nationwide *Jinshin-koseki* in 1871 makes it possible to measure the random genetic drift that has taken place in Japan in the last century, during which time names have been transmitted regularly from parent to child.

Acquisition of surname. A person legally acquires his surname at birth. Ordinarily a child takes the surname of his father (patrilineal inheritance), but under some circumstances the mother's name is taken (matrilineal inheritance). Illegitimate children usually take the name of the mother; however, such cases are not included in this study. The only exception is in the case of a rare foundling whose parents are unknown, when a surname is given by the magistrate at the place where the child was found. No such cases are included in this study.

Change of surname. Japanese family registration law (see [7]) says that a couple shall have only one family name, which is either the husband's or wife's surname before marriage but not both. Usually the female takes her husband's name at marriage. If divorce or separation by death occurs, the individual who changed his surname either retains the family name or returns to his original surname. If a child is adopted into a family, his surname will be the family name of his foster parents. A special custom in Japan is *muko-yoshi*, which maintains the family name through many generations; when a couple does not have a son but has daughters, a bridegroom-to-be is adopted just before marriage takes place. This then leads to matrilineal transmission of the surname. In the present paper, we will define the surname of a person as his or her family name at the time of birth.

SUBJECTS AND METHODS

The data to be analyzed here were collected by author Furusho in 1963. A set of data consists of 714 pedigrees going back as many as five generations, starting from propositi who were sixth-grade students at all elementary schools in the city of Ohdate, Akita prefecture. Another set, collected by the same method, consists of 518 pedigrees from the city of Mine, Yamaguchi prefecture. Since nearly all children attend school in Japan, we believe that each sample includes practically all 12-year-old boys who lived in each city at the time of the investigation. Only males were studied because the data were originally gathered for another study which included only males. The city of Ohdate, whose area is 320 km², is inhabited by about 60,000 people. The main occupations are farming and commerce, and Ohdate may be considered representative of small cities in northeastern Japan. On the other hand, Mine, with an area of 221 km², is inhabited by about 35,000 people whose main occupation is mining, so that many workers have come from other parts of Japan. The city of Mine is therefore representative of small cities in Japan with high migratory activity. For each boy, inbreeding has been investigated retrospectively not only through an interview, asking about all possible consanguineous unions and genetic relationships among relatives, but also through *koseki* or household records which give parents' names, birthplaces, dates of birth, children of both sexes in chronological order, and other relevant events such as adoption, marriage, and divorce (for details on *koseki*, see [8]).

The surname of each person was compared with the family name given in *koseki*. Except for foundlings and illegitimates, the agreement was satisfactory. The surnames were then transformed from Chinese characters to Roman spellings for analysis by electronic computer. A difficulty encountered in coding is the fact that several different pictorial letters correspond to the same phonetic signs and can be read in several ways. This problem was avoided by minor changes of spelling. Individuals whose particular locations in a pedigree are designated by numbers from 1 to 14 (fig. 1) are encoded in 10 columns of two punch cards. The number 0 is assigned to propositi. Also, 10 minus signs are assigned to persons with unknown surnames because of loss of record, illegitimacy, or abandonment, and to avoid duplication of parental location for persons who appear two times because of consanguinity. The tests of significance have been performed using the $2 \times N$ contingency χ^2 [9].

RESULTS

Frequency of surname. In Ohdate, 8,744 persons among 9,970 individuals had known surnames. There were 816 different surnames of which Sato, a popular surname in northeastern Japan, was the most common (5.64%). Then, Hatakeyama (3.97%), Sasaki (2.77%), Ito (2.20%), and Sugahara (2.01%) follow as popular surnames (table A1). These five most common names contribute 0.0067 to Σq_i^2, the expected frequency of isonymy in random pairs, in which q_i is the proportion of the *i*th name in the population with total $\Sigma_i^2 = 0.0118$. On the other hand, the number of unique surnames which appear only once is 247 or 2.82%. Their contribution to Σq_i^2 is nearly negligible.

In Mine, 6,313 persons among 7,252 individuals had known surnames. There were 1,392 different names of which Yamamoto, a popular name in Japan, was the most common (2.22%). Then, Tanaka (1.31%), Ito (1.22%), Yamada (1.17%) and Nakamura (1.00%) follow as popular surnames (table A2). Note that the kinds of common names are different from those in the city of Ohdate. These five common names contribute 0.00154 to Σq_i^2, with total $\Sigma q_i^2 = 0.00335$. The number of unique surnames which appear only once is 526 or 8.33%. Although their contribution to Σq_i^2 is nearly negligible, such a high frequency reflects the diverse origins of surnames.

Change of surnames. Adoption, illegitimacy, and abandonment are the main causes of a break in surname transmission. In this sense, they play the role of mutation for surnames. However, not all cases lead to such a result. Therefore the real parent-offspring relationships are identified, and then examinations are made to see whether the child's surname is different from both parents. Table 1 shows the observed proportions of broken surname inheritance for seven trios *A*, *B*, *C*, *D*, *E*, *F*, and *G*. Except for *G* in which propositi are included, the rate of such events in Ohdate is 6.19% (a pooled value). The high rate in *G* is unexpected. In Mine the rate of occurrence is 13.23% (a pooled value, not including *G*), nearly two times as high as the one observed in Ohdate. Apparently, migrants adopt children more often. No significant difference is observed between two generations; namely, $A + B + C + D$ com-

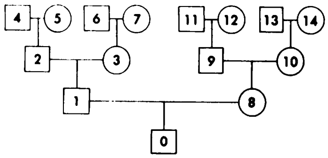

FIG. 1.—Individuals who would be assigned by surname 0 through 14 in pedigree. 0 = propositus; □ = male; ○ = female; generation numbers are assigned I for oldest, II for middle, and III for generation of individuals 1 and 8.

TABLE 1

OBSERVED NUMBER OF CHILDREN WHOSE SURNAMES ARE DIFFERENT FROM BOTH PARENTS

Parents and Child	Observed No./No. of Children		Parents and Child	Observed No./No. of Children	
	Ohdate	Mine		Ohdate	Mine
A (4, 5) 2**	30/508	55/465	*E (2, 3) 1*	43/661	44/409
B (6, 7) 3	23/507	50/358	*F (9, 10) 8*	43/675	61/416
C (11, 12) 9	31/551	51/376	*G (1, 8) 0*	93/706	46/497
D (13, 14) 10	44/551	06/477	...	...	...
	Observed Proportion				
$A+B+C+D$	0.0604	0.1348	$A+B+C+D+E+F$	0.0619	0.1323
$E+F$	0.0643	0.1273	$A+C+E$	0.0604	0.1280
G	0.1317	0.0926	$B+D+F$	0.0634	0.1370

* Numbers for parents and child refer to positions indicated in fig. 1.

pared with $E + F$ gives a heterogeneity χ^2 of 0.2479 in Ohdate and 0.1892 in Mine (df = 1). Slightly higher rates are observed for female children ($B + D + F$) than for male ($A + C + E$), but the difference is not significant in either city ($\chi^2 = 0.016$ in Ohdate and $\chi^2 = 0.411$ in Mine with df = 1).

Proportion of matrilineal transmission of surnames. There are four types of parent-offspring relationships by sex: father-son, father-daughter, mother-son, and mother-daughter. The rates of surname identity are shown in table 2. In the latest generation of Ohdate, mother-child isonymy, that is, proportion of matrilineal transmission of surname, is 21%, which is significantly less than that value in the previous generation (28%). This decrease of matrilineal transmission may be due to an increase of migratory activity. No heterogeneity is observed for father-son identity, while father-daughter isonymy is significant within and between generations. The latter is due to the low proportion of great-grandfather–grandmother transmission ($13 \rightarrow 10$) for unknown reasons. On the other hand, in Mine the mother-child isonymy is nearly constant over the last two generations, with the figure 0.1387 (a pooled value), a proportion half that of Ohdate. This is understandable because of the nature of the Mine population, where changes of names are twice as frequent as in Ohdate.

The presence of both types of name transmission, however, does not affect the total frequency of isonymous consanguineous unions, although they are distributed differently in the subtypes of consanguineous matings. For example, only one of four subtypes of first-cousin unions is expected to be isonymous in either a completely patrilineal or matrilineal system. In mixed systems (as the present one), isonymous unions would be distributed among the four subtypes of first-cousin marriages as $(1 - m)^2/4 : (1 - m)m/4 : m(1 - m)/4 : m^2/4$, where m is the proportion of matrilineal inheritance for surnames. Ten isonymous unions among 34 first-cousin marriages in

TABLE 2

PROPORTION OF SURNAME CONCORDANCE BETWEEN PARENT AND CHILD

♂→♂	Rate (N)*	♂→♀	Rate (N)	♀→♂	Rate (N)*	♀→♀	Rate (N)
	Ohdate						
4†→*2*†	0.7860(570)	*6*→ *3*	0.8169(557)	*5*→*2*	0.2960(544)	*7*→ *3*	0.2672(539)
11→*9*	0.7858(593)	*13*→*10*	0.7416(518)	*12*→*9*	0.2786(585)	*14*→*10*	0.3016(567)
Pooled	0.7929	....	0.7798‡	....	0.2869	....	0.2848
2→*1*	0.8050(682)	*9*→ *8*	0.7922(693)	*3*→*1*	0.2124(678)	*10*→ *8*	0.2075(689)
	Mine						
4→*2*	0.7423(392)	*6*→ *3*	0.7696(407)	*5*→*2*	0.1567(383)	*7*→ *3*	0.1472(394)
11→*9*	0.7859(439)	*13*→*10*	0.7398(442)	*12*→*9*	0.1435(425)	*14*→*10*	0.1586(435)
Pooled	0.7653	....	0.7538	....	0.1497	....	0.1532
2→*1*	0.7866(478)	*9*→ *8*	0.7694(490)	*3*→*1*	0.1067(478)	*10*→ *8*	0.1270(488)

* The sum of corresponding rates does not have to be 1 since both parents' names are not always identified for a given child whose surname is known.

† Numbers for parent and child refer to positions indicated in fig. 1.

‡ The χ^2 for within generation is signiffcant, namely, the pair (*13, 10*) is significant from the others [(*6, 3*) and (*9, 8*)].

Ohdate are distributed among the four subtypes as shown in table 3. Since the observed number is small, all within a generation are pooled so that the expectations are computed for $m = 0.21$ and 0.28. The total number of isonyms is slightly higher than the expected one-fourth of the first-cousin marriages, but not significantly so. Although the sample size is small in Mine, it is suspected that the low proportion of the total isonymy might be due to a high frequency of migration; however, the conclusion requires further study.

The above conclusion must be true for most human pedigrees. Assuming random patrilineal or matrilineal transmission of surname, even cousins have an inbreeding coefficient $f = (1/2)^{2n+2}$ and the expected isonymy is $I = [(p + m)^2/4]^n$, so that $I = 4f$, where n is the degree of the cousins; $n = 0$ for sibs, $n = 1$ for first cousins, $n = 2$ for second cousins, and so on. In the case of odd cousins, we have $f = (1/2)^{2n+1}$ and $I = [(p + m)^2/4]^{n-1}(p/2 + m/2) = (1/2)^{2n-1}$, so that again $I = 4f$, where $p = 1 - m$ ($n = 1$ for uncle-niece, $n = 2$ for first cousin once removed, etc.). The relation $I = 4f$ also holds for double even cousins in the presence of both types of name transmission except double first-cousin marriages. In this case, strict adherence to the Japanese custom of *muko-yoshi* will force the family not to have an isonymous union, since in a family without a son, if an elder sister keeps her family name, it is usual that a younger girl takes her stepbrother's name. Therefore, in double first-cousin marriage, maternal transmission of name destroys the relation $I = 4f$. However, the occurrence of double first-cousin marriage is usually very rare. Furthermore, in a large sibship in the old days in Japan, it was usually not necessary to take *muko-yoshi*, so that the biasing effect of *muko-yoshi* in estimating the inbreeding coefficient from isonymy study is probably very small.

TABLE 3

DISTRIBUTION OF ISONYMOUS MARRIAGES AMONG FOUR SUBTYPES OF FIRST-COUSIN UNIONS

	SUBTYPE				TOTAL
	□—□ / □=○	□—○ / □=○	○—□ / □=○	○—○ / □=○	
	Ohdate				
N	12	4	14	4	34
I_o	5	2	2	1	10
$I_e(m=0.21)$	5.3	1.4	1.4	0.4	8.5
$(m=0.28)$	4.4	1.7	1.7	0.7	8.5
	Mine				
N	1	6	5	9	21
I_o	...	...	1	...	1
$I_e(m=0.14)$	3.89	2.51	2.51	0.10	5.25

NOTE.—N = observed no. first-cousin marriages; I_o = observed no. isonyms; I_e = expected no. isonyms; m = proportion of matrilineal inheritance for surnames.

Observed number of isonymous pairs for surnames. In computing the estimated proportions of surnames, the probability of isonymy in the sample is

$$I_e = \frac{\Sigma\binom{n_i}{2}}{\binom{N}{2}} = \frac{\Sigma n_i(n_i - 1)}{N(N-1)} = \frac{N}{N-1}\left(\Sigma q_i^2 - \frac{1}{N}\right),$$

where n_i is the number of persons with the ith surname, N is the size of sample, and $q_i = n_i/N$. When all surnames in the pedigrees are pooled, I_e(all) = 0.0125 and 0.0033 in Ohdate and in Mine, respectively, while in specific relationships between two locations in the pedigree the figures are I_e (pair) = 0.010 ~ 0.015 in Ohdate and 0.0026 ~ 0.0054 in Mine. The Mine figures are somewhat more variable than those of Ohdate. Also, in both cities, the observed isonymous pairs are significantly more frequent than would be expected from random pairing. This means that nonrandom inbreeding is occurring in these populations.

Occurrence of isonymous marriages. The occurrence of isonymous marriages in both cities decreases linearly with generation (table 4 for Ohdate and table 5 for Mine, in which one-fourth of isonymy is given). The regression coefficients on generation in Ohdate is $b = -0.0399$ with $\chi^2 = 45.74$ (df = 1), and in Mine, $b = -0.0157$ ($\chi^2 = 12.76$ with df = 1). Both of these account for almost all the χ^2 of 46.94 for Ohdate and 12.77 for Mine (df = 2). No heterogeneity is observed within a generation. This trend reflects the reduction of consanguinity over the last three generations, presumably due to avoidance of consanguineous marriage and to increased migration.

TABLE 4

PROPORTION OF OBSERVED ISONYMOUS MARRIAGES AND FREQUENCY OF EXPECTED MATCHES BY RANDOM PAIRS, OHDATE

Generation and Couple	Proportion of Isonymy	$\Sigma q_m q_f$	Σq_m^2	Σq_f^2	Σq_{m+f}^2	I_e (pair)
I:						
(*4, 5*)*	0.1142(508)†	0.01224	0.01362	0.01321	0.01316	0.01329
(*6, 7*)	0.1203(507)	0.01273	0.01485	0.01505	0.01369	0.01347
(*11, 12*)	0.1216(551)	0.01149	0.01314	0.01194	0.01200	0.01125
(*13, 14*)	0.1125(551)	0.01200	0.01394	0.01358	0.01291	0.01204
Pooled	0.1172	0.01183	0.01261	0.01202	0.01208	0.01272
II:						
(*2, 3*)	0.0801(662)	0.01205	0.01193	0.01438	0.01297	0.01323
(*9, 10*)	0.0667(675)	0.01082	0.01151	0.01340	0.01163	0.01152
Pooled	0.0733	0.01130	0.01133	0.01331	0.01181	0.01243
III:						
(*1, 8*)	0.0385(701)	0.01070	0.01078	0.01145	0.01143	0.01162

NOTE.—q_m = proportion of certain surname in males; q_f = proportion of certain surname in females; q_{m+f} = proportion of certain surname in the population; I_e (pair) = expected isonymy from a unique sample (see text).

* Numbers for couples refer to positions indicated in fig. 1.

† Total no. of couples.

TABLE 5

TOTAL INBREEDING COEFFICIENT (F_{IT}), MINE

Generation and Couple	No. of Couples	F_{IT}	Pooled by Generation
I:			
(*4, 5*)*	358	0.01048	0.01090
(*6, 7*)	376	0.01196	
(*11, 12*)	409	0.00978	
(*13, 14*)	416	·0.01142	
II:			
(*2, 3*)	465	0.00807	0.00690
(*9, 10*)	477	0.00576	
III:			
(*1, 8*)	489	0.00307	0.00307

* Numbers for couples refer to positions indicated in fig. 1.

This is a different finding from a Peruvian population [10] in which no decreasing trend of isonymy was observed over the three generations.

Isonymous marriages take place in a relatively small area. In the city of Ohdate, the distribution of isonymy by marital distance (r) for the parental generation is given in table 6; distance is measured along actual movement rather than as a straight line between birthplace of mates. This was determined by interview and was based primarily on railway distance and distance from birthplace to the railway station. Twenty-three of 26 isonymous unions have marital distances not greater than 25 km. The relationship between frequency of isonymy (I) and marital distance (r) was markedly leptokurtic. The data could be fitted well by the empirical distribution $I = Cr \exp(-a \cdot r^{1/4})$, in which $C = 6.8 \times 10^7$ and $a = 20.47$/km from a graphic method. For distances greater than 25 km, isonymy seems to occur at random.

TABLE 6

DISTRIBUTION OF FREQUENCY OF ISONYMY AND MARITAL DISTANCE, OHDATE

Distance (r) (km)	Frequency (No. of Couples)
0	0 (2)
0 ~ 0.5	0.2448 (49)
0.5~ 1.0	0.1282 (5)
1.0~ 4.0	0.0126 (158)
4.0~ 9.0	0.0140 (142)
9.0~25.0	0.0052 (190)
25.0~36.0	0.0312 (32)
36.0~49.0	0.0500 (20)
49.0~64.0	0 (12)
64.0~81.0	0.0909 (11)
>81.0	0 (93)

The inbreeding coefficient. The inbreeding coefficient is estimated as follows. Let I be the observed proportion of isonymous marriages and I_r the proportion of isonymous pairs by random matches. Then we introduce three inbreeding coefficients: F_{ST}, F_{IS}, and F_{IT} [11]. The F_{ST} is a measure of isonymy that occurs from random unions within the population and is therefore a function of name frequency only; F_{IS} is the excess beyond F_{ST} caused by nonrandom marriages; and F_{IT} is the total inbreeding coefficient from both causes. The random isonymous pair (I_r) can be computed from either $\Sigma q_m q_f$, Σq_m^2, Σq_f^2, Σq_{m+f}^2, or I_e (pair), where q_m, q_f, and q_{m+f} are frequencies of certain surnames in male, female, and total population, respectively. Noting that $F_{ST} = I_r/4$ and $F_{IT} = I/4$, the nonrandom inbreeding coefficient F_{IS} is obtained from $F_{IS} = (F_{IT} - F_{ST})/(1 - F_{ST})$.

This differs slightly from the earlier formulation [1], but was suggested by Prof. J. F. Crow as probably being more appropriate. In this new formulation, I and I_r which are calculated directly from the data are used to compute F_{IT} and F_{ST}. Then these are used to compute F_{IS} from Wright's equation relating F_{IT}, F_{IS}, and F_{ST}. This includes no correction for adopted children and therefore assumes that the consanguinity rate among their true parents is the same as among the parents in our samples.

Table 7 summarizes estimates of F_{ST} in Ohdate by five different methods. It is

TABLE 7

INBREEDING COEFFICIENT DUE TO RANDOM MATCHES (F_{ST}), OHDATE

Generation	Method 1	Method 2	Method 3	Method 4	Method 5
I...........	0.00295	0.00314	0.00301	0.00302	0.00318
II..........	0.00282	0.00282	0.00333	0.00290	0.00311
III.........	0.00268	0.00270	0.00286	0.00286	0.00290

NOTE.—Method 1, computed from $\Sigma q_m q_f$; method 2, computed from Σq_m^2; method 3, computed from Σq_f^2; method 4, computed from Σq_{m+f}^2; method 5, computed from I_e (pair).

remarkable that random inbreeding is nearly constant for the last three generations. On the other hand, the total inbreeding coefficients F_{IT} are 0.0293 for the grandparents, 0.0183 for the parents, and 0.0096 for the filial generation, showing a decreasing trend of inbreeding. This is mainly due to nonrandom inbreeding (table 8).

The total inbreeding coefficients in Mine are given in table 5 for all couples in the pedigree. Since many migrants are included in the ancestral generations, we had expected to have different estimates even within a generation. However, the results show rather similar estimates. This suggests that many migrants come at random from all parts of Japan. Incidentally, it is of interest that the total inbreeding coefficients F_{IT} in Mine are one-third of those in Ohdate, despite the smaller population size in Mine. Random and nonrandom inbreeding coefficients are shown in tables 9 and 10, respectively. It is impressive that random inbreeding is nearly constant through the century, as seen in the city of Ohdate.

DISCUSSION

The use of the frequency of identical surnames may introduce biases in either direction for the estimate of the inbreeding coefficient [1, 12]. However, our interest is not in the value itself but in the difference between the estimates. Any bias introduced in

TABLE 8

INBREEDING COEFFICIENT DUE TO NONRANDOM MATCHES (F_{IS}), OHDATE

Generation	Method 1*	Method 2	Method 3	Method 4	Method 5
I	0.02643	0.02624	0.02637	0.02636	0.02620
II	0.01551	0.01554	0.01504	0.01546	0.01526
III	0.00696	0.00694	0.00678	0.00678	0.00674

* See table 7 for description of methods.

TABLE 9

INBREEDING COEFFICIENT DUE TO RANDOM MATCHES (F_{ST}), MINE

Generation and Couple	Method 1*	Method 2	Method 3	Method 4	Method 5
I:					
(*4, 5*)†	0.00074	0.00138	0.00144	0.00107	0.00080
(*6, 7*)	0.00073	0.00121	0.00134	0.00100	0.00077
(*11, 12*)	0.00075	0.00134	0.00128	0.00103	0.00077
(*13, 14*)	0.00088	0.00164	0.00148	0.00121	0.00093
Pooled	0.00076	0.00090	0.00093	0.00084	0.00080
II:					
(*2, 3*)	0.00074	0.00136	0.00120	0.00101	0.00082
(*9, 10*)	0.00080	0.00121	0.00153	0.00108	0.00091
Pooled	0.00077	0.00099	0.00109	0.00091	0.00083
III:					
(*1, 8*)	0.00071	0.00134	0.00121	0.00100	0.00081

* See table 7 for description of methods.

† Numbers for couples refer to positions indicated in fig. 1.

TABLE 10

INBREEDING COEFFICIENT DUE TO NONRANDOM MATCHES (F_{IS}), MINE

Generation and Couple	Method 1*	Method 2	Method 3	Method 4	Method 5
I:					
(4, 5)†	0.00975	0.00911	0.00905	0.00942	0.00969
(6, 7)	0.01124	0.01076	0.01063	0.01097	0.01120
(11, 12)	0.00904	0.00845	0.00851	0.00876	0.00902
(13, 14)	0.01055	0.00980	0.00995	0.01022	0.01050
Pooled	0.01015	0.01001	0.00998	0.01007	0.01011
II:					
(2, 3)	0.00734	0.00672	0.00688	0.00707	0.00726
(9, 10)	0.00496	0.00456	0.00424	0.00469	0.00485
Pooled	0.00613	0.00592	0.00582	0.00560	0.00608
III:					
(1, 8)	0.00236	0.00173	0.00186	0.00207	0.00226

* See table 7 for description of methods.
† Numbers for couples refer to positions indicated in fig. 1.

the estimate itself disappears in such comparisons, so that a trend of inbreeding can be ascertained correctly. In the present study, random inbreeding is nearly constant over the last three generations (for the last century), though there may be a slight decrease in recent years. This is a rather surprising finding because we expected different surname distributions by generation due to increased migration. Presumably, the immediate effect of migration appears only in nonrandom inbreeding and has not affected the distribution of names in the population.

The near constancy of random inbreeding suggests the following. At equilibrium, applying the island model of Wright, we have $F_{ST} = 1/(1 + 4N_em)$, so that $N_em =$ 250 for Mine and $N_em = 83$ for Ohdate, where N_em is the effective number of migrants. Although the absolute numbers may contain some biases, the effective number of migrants is three times larger in Mine than in Ohdate, again confirming higher migratory activity in Mine. Also, the fact that $4N_em \gg 1$ suggests that there are very slight local differences, and that the entire population behaves essentially as a single panmictic unit [11].

Wright [11] has also shown that if σ is the standard deviation of gene dispersion along one coordinate and t the number of generations, then the correlation coefficient between gene frequencies of neighborhoods at an average distance apart of about $\sigma\sqrt{t}$ relative to the total population is given approximately by the ratio of F_{ST}/F_{IT}, which is equivalent to the ratio of I_r/I in terms of isonymy. Data from Mine as well as Ohdate have shown an exponential relation between correlation and distance (fig. 2). This is a practical confirmation of the expected drop in the correlation between the gene frequencies of local populations according to the distances that separate them.

Although we employed five methods for estimating F_{ST}, the quantity $\Sigma q_m q_f$ is most suitable for the estimation of random inbreeding since it reflects actual occurrence of random isonymy among potential mates. If the frequency distributions of names are the same in both sexes, then $\Sigma q_m q_f = \Sigma q_m^2 = \Sigma q_f^2 = \Sigma q_{m+f}^2$. As shown in table 4, the Ohdate data nearly satisfy this relation, indicating that random genetic

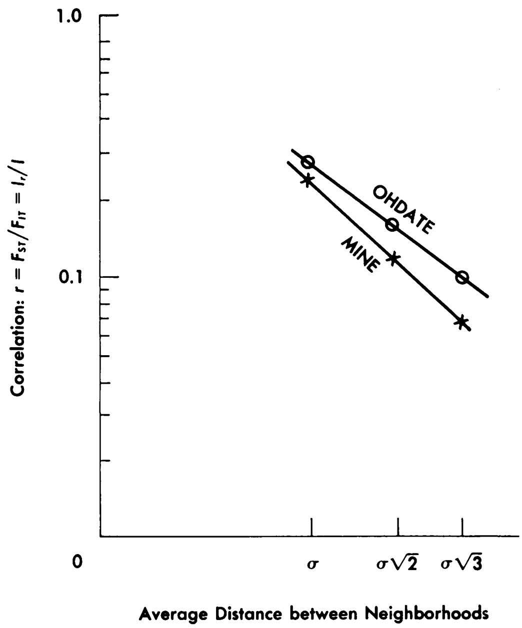

FIG. 2.—Relationship between correlation of gene frequencies and size of neighborhoods in Wright's sense. r = correlation coefficient; F_{ST} = inbreeding coefficient measuring isonymy from random unions; F_{IT} = total inbreeding coefficient; I = observed proportion of isonymous pairs; I_r = proportion of isonymous pairs by random matches.

drift is of similar magnitude in both sexes. If the distributions are significantly different, Σq_m^2 will differ from Σq_f^2, especially whenever common names differ in the two. However, such differences will disappear at equilibrium when random mating with respect to surnames continues, as is certainly the case in the human population. The last quantity, I_e, will be smaller than Σq_{m+f}^2 in isolated populations, but no significant difference will be observed in a large population, as in the case in Ohdate.

On the other hand, we have observed in Mine the relation I_e (pair) $\doteq \Sigma q_m q_f < \Sigma q_m^2 = \Sigma q_f^2 = \Sigma q_{m+f}^2$ among the five probabilities of random pairs. This is mainly due to differences in kinds of surnames between sexes, although the proportions of random isonymy within each sex remains nearly the same. One cause of this may be that many men who were from other parts of Mine have been employed as seasonal workers at mines but have remained, while movements of women might have been different, perhaps smaller. Therefore, several different kinds of surnames have been introduced in Mine by males. The relation also indicates that the probability of isonymy in the sample (I_e) gives very similar values to that of $\Sigma q_m q_f$. Since the computation of I_e is easier than that of $\Sigma q_m q_f$, the quantity I_e may be used for the estimation of the random inbreeding coefficient F_{ST}. Note, however, that the five methods give very similar estimates for the nonrandom inbreeding coefficient F_{IS}.

While the random component of inbreeding has not changed over the last three generations, the inbreeding coefficient F_{IS} due to nonrandom marriages decreased strikingly with time. This is mainly due to a recent trend of increased immigration, but also to avoidance of consanguinity. In the study of migratory functions, the variances of parent-offspring distances increased with time. On the other hand, pedigree analysis in Ohdate, for instance, shows a decreased tendency for inbreeding, namely, the mean inbreeding coefficients are 0.0020 for the grandparental generation and 0.0013 for the parental generation. Thus, nonrandom inbreeding was more common in former times; that is, nonrandom components are 14 times, 9 times, and 4 times higher than the random component in the first, second, and third generation, respectively. The corresponding figures in Mine are 12 times, 7 times, and 2 times, respectively.

Although our interest has been primarily directed to the comparison of the inbreeding coefficients at different times, it may be informative to discuss the relative magnitude of biases in the estimate. Generally speaking, the assumption of a unique origin for all surnames causes serious overestimation of the inbreeding coefficients. For example, in Ohdate, if all 714 individuals have had different ancestors, then we have $F_{ST} = 1/(4 \times 714) = 0.00035$, which is one-tenth of the value obtained from the previous assumption. The true inbreeding coefficient F_{ST} may therefore lie between 0.00035 and 0.003. With this uncertainty, the correction of 6% due to changing surnames could ne negligible. Furthermore, some isonymy may reflect independent origin of surnames rather than common ancestry, in which case F_{IT} is an overestimate. That is, total inbreeding coefficients obtained from isonymy study give an upper limit of human inbreeding.

SUMMARY

Random and nonrandom components of inbreeding have been investigated through isonymy study in the cities of Ohdate in northeastern Japan and Mine in western Japan. It was found that random inbreeding was nearly constant over the last three generations (for the last century), while the inbreeding coefficient due to nonrandom marriages decreased with time. Thus, nonrandom inbreeding has been very important in the past. It was also observed that change of surnames occurred in 6.19% of the persons in Ohdate and in 13.23% in Mine. Furthermore, it was shown, practically and theoretically, that the existence of both patrilineal and matrilineal transmission of names does not affect the relation $I = 4f$, where I is the proportion of isonymous marriages and f is the inbreeding coefficient.

A comparison of results from the two cities demonstrated the following: an increase in changes of surnames, a decrease in the proportion of matrilineal inheritance of surnames, and, of course, a decrease in the frequency of consanguineous marriages. These findings primarily result from increased migration. However, none of these findings seem to affect seriously the constancy of random inbreeding.

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APPENDIX

TABLE A1

SURNAME DISTRIBUTION IN CITY OF OHDATE IN NORTHEASTERN JAPAN (POOLED FOR THREE GENERATIONS)

n_i	f_i	n_i	f_i	n_i	f_i	n_i	f_i
1	247	21	2	44	2	96	1
2	157	22	1	45	1	97	1
3	108	23	3	47	1	101	1
4	40	24	2	49	1	104	1
5	28	25	3	50	2	115	1
6	25	26	2	51	1	118	1
7	22	27	1	54	1	121	1
8	17	28	4	61	1	127	1
9	13	29	1	64	1	134	1
10	16	30	1	68	1	140	1
11	9	31	1	77	1	148	2
12	7	32	3	82	1	176	1
13	8	33	1	84	1	193	1
14	7	35	1	85	1	231	1
15	9	37	2	87	1	243	1
16	5	38	1	88	1	348	1
17	3	39	2	89	1	494	1
18	5	40	3	90	1	1,232	Unknown
19	8	41	2	91	1		
20	3	42	2	94	1		

NOTE.—Total no. of persons = 9,970; no. of kinds of surnames = 816; n_i = no. of persons whose surname is the same; f_i = kinds of surnames.

TABLE A2

SURNAME DISTRIBUTION IN CITY OF MINE IN WESTERN JAPAN (POOLED FOR THREE GENERATIONS)

n_i	f_i	n_i	f_i	n_i	f_i
1	526	18	4	40	1
2	277	19	6	41	1
3	203	20	7	42	2
4	92	22	2	43	3
5	55	23	1	44	1
6	42	25	1	46	1
7	30	27	3	49	2
8	17	28	2	51	2
9	12	29	1	55	1
10	16	30	1	57	1
11	12	31	2	58	1
12	9	32	3	63	1
13	12	33	3	74	1
14	12	34	1	77	1
15	3	36	1	83	1
16	4	37	3	140	1
17	5	38	3	939	Unknown

NOTE.—Total no. of persons = 7,252; no. of kinds of surnames = 1,392; n_i = no. of persons whose surname is the same; f_i = kinds of surnames.

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