

LINKAGE RELATIONS OF THE BLOOD GROUP GENES OF MAN

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Introduction.—The results to date are here given of a search for linkage between the genes for human blood groups, for phenyl thio-carbamide tasting and for sex. The calculations are based on 487 families with two or more children. The blood grouping tests were done between 1938 and 1951 by this Unit or by its parent, the Galton Laboratory Serum Unit, established by Professor R. A. Fisher, with the support of the Rockefeller Foundation. Many of the families have appeared in papers from the two Units, but with those groups alone recorded which were appropriate to the particular study.

The u statistics of Fisher (1935*a*, 1935*b*) have been applied to the pedigrees, which have been treated as “data for the double back-cross”. Thus, we have scored the “certain” families of Finney (1940) which fall into the “mating types” 20 and 21. Since these pedigrees can be analysed in so many ways, we hope that it may be possible to make available the complete collection, including one-child families.

The earlier families could of course be tested for relatively few characters and consequently contribute much less to the general amount of information than do the hundred or so families which have been tested for the nine blood group systems now known. The point may be laboured thus: five of the recent families, taken at random, afford a total κ of 85; had they been counted in 1939 for *ABO*, *MN*, *P*, *P.T.C.* and sex alone, the total κ would have been 14.

Conclusions.—Our results are shown in the table; they disclose no likely linkages though the amount of information in many of the comparisons is small enough to leave plenty of room for future detection. In making so many counts it is to be expected that some of them will by chance approach significance at the 1 in 20 level, and in two comparisons, that between *P* and *Duffy* and that between *Duffy* and *Kidd*, $S(\lambda)$ is just greater than $1.64\sqrt{S(\kappa)}$. In both these counts information is small and addition of the “doubtful” families (Finney, 1940) makes $S(\lambda)$ less than $1.64\sqrt{S(\kappa)}$.

Discussion.—Our results, where they overlap, support the findings of previous workers. Many of the past investigations have been confined to the testing of pairs of sibs. The most numerous *family* blood group results which have been analysed for linkage are: 166 families tested

Linkage scores of the "certain" families amongst the 487;
the upper figure showing $S(\kappa)$, the lower $S(\lambda)$

	P.T.C.	Kidd	Duffy	Lewis	Kell	Luth.	Rh	P	MNS	ABO
Sex	27 -1	22 +4	48 +4	96 -6	85 -5	32 +8	665 -43	110 +6	718 0	515 +3
ABO	24 +4	28 0	51 -3	71 +15	27 -1	41 -5	313 +7	54 +2	402 +16	
MNS	38 -10	31 -1	62 +6	49 +1	65 -5	40 -6	481 +27	97 -15		
P	5 -3	— —	10 +6	20 0	6 -2	7 -1	95 -1			
Rh	19 +1	23 +5	59 -5	65 +3	66 -12	35 -3				
Lutheran	2 -2	3 +1	16 -4	4 0	— —					
Kell	4 +2	6 0	8 -2	10 -2						
Lewis	5 -3	2 +2	18 0							
Duffy	7 -1	3 +3								
Kidd	8 +2									

for ABO and MN by Landsteiner and Levine (1928) and analysed by Wiener (1932), 131 families analysed for ABO and MN by Wiener and Vaisberg (1931), 66 families analysed for ABO and MN by Zieve, Wiener and Fries (1936), 30 families tested for ABO, MN, P.T.C. and sex by Boyd and Boyd (1941) and analysed by Finney (1941) and 60 families tested for ABO, MN and Rh (Rh positive and negative) by Landsteiner and Wiener (1941) and analysed, with 40 more families, by Wiener and Sonn (1943).

Mohr (1951a and b) has produced very strong evidence of linkage between the Lutheran genes and the Lewis genes. This was first detected by the sib method of Penrose (1946) and, after the testing of 17 complete families selected for possessing the antigen Lu^a , it was shown too by the u statistics. By neither method of analysis do our own families give any hint of the linkage, but this is one of the comparisons for which our information is slight.

That linkage between two genes is not detectable when "information" is adequate does not necessarily mean that they are not on the same chromosome, but it does mean that if they are on the same chromosome they must be so far apart that the linkage is not likely to be detected until a third gene is found within demonstrable linkage distance of both. Bearing this qualification in mind, it is clear from

our results that none of the genes for the 9 blood group systems, or for P.T.C. tasting is partially sex-linked. It is also clear that the genes for *ABO*, *MNS* and *Rh* are not linked to each other or to the genes for *P*, *Lutheran*, *Kell*, *Lewis*, *Duffy*, *Kidd* or P.T.C. The information is somewhat inadequate in most of the remaining 21 of the 55 comparisons.

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