Reports and Letters

Genetic Recombination in Bacteria

In the issue for 12 Aug. *Science* (p. 278) reported on the work of Wollman and Jacob on genetic recombination in *Escherichia coli*. This work concerned the effects of mechanical disruption of mating cultures on the patterns of segregation. The authors interpreted their results in terms of fractional fertilizations by broken gametic units, whose passage into the fertilized bacterium is specifically polarized. The news report further correlated this effect with virus-mediated genetic transduction. These findings are extremely interesting, but a report on a single article cannot take the space to discuss diverse interpretations. This danger is underlined by the fact that previous news summaries [*Science* **118**, 66 (17 July 1953)] have reported claims that recombination in *E. coli* K-12 depends on an F+ "virus" that acts as the vector; the present article refers to "mating pairs" and could not discuss the evolution in hypotheses. This letter is intended as an extension of the remarks of the news report that presents a more complete picture.

Transduction, as the term was defined when first introduced, is the transfer of a fragment of genetic material by phage or any other agency; fertilization implies the union of whole genomes or nuclei. Intermediate categories of genetic exchange may be found to occur naturally, or as suggested by the current article, may be artificially produced. For example, fractional fertilizations (or postzygotic losses with the same effect) have been indicated in frog eggs by sperm treated with toluidine blue [R. Briggs, *J. Gen. Physiol.* **35**, 761 (1952)] and this might be speculated on as one approach to the achievement of genetic transduction in higher organisms. However, the artificial interruption of fertilization serves, if anything, to emphasize the completeness of the normal process and the consequent distinction between fertilization and transduction mechanisms.

Unfortunately, the true constitution of the fertilized cell cannot be inferred with certainty from data on haploid segregants, owing to peculiarities of the meiotic mechanism in *E. coli* K-12. In the cited experiments, fertilization might have been incomplete, or it might have been complete with later disturbances of chromosome pairing to account for the segregation effects. Furthermore, if fertilization were fractional, the gradient of recovery of various loci might be due, as proposed, to the preferential orientation of gametic chromosomes, or to dependence on one locus (a centromere?) for the completion of synapsis, crossing-over and segregation.

These limitations of inference are equally applicable to undisturbed matings and have provoked a diversity of hypotheses that share the concept that the Hfr or F+ gametes are normally incomplete and variable in their genetic content. However, all the experimental data on haploid segregants are equally consistent with a second hypothesis that fertilization is regularly complete, but is coincident with chromosome breakage at specific, predetermined points on the F+ chromosome, so that certain segments are deleted after meiosis. Even small deletions would be lethal in haploid segregants and would influence the entire segregation pattern.

The most direct means of analyzing the intermediate processes of recombination and deciding between these conflicting viewpoints lies in the behavior of nondisjunctional types, which have been found both for sexual fertilization (heterozygous diploids) and a phage-mediated transduction (heterogenotes) in *E. coli* K-12. Thus the heterogenotes have helped to clarify the nature of the fragments in transduction, while the heterozygotes support the second hypothesis that in sexual recombination, the losses are postzygotic. The evidence is that the losses sometimes involve segments of the F- rather than the F+ or Hfr chromosome, or even cross-overs between them, and must therefore be preceded by complete fertilization, synapsis, and crossing-over. When the chromosomes are first broken is not known, and this may occur in the Hfr gamete, although the losses ordinarily (perhaps not always) occur later, after meiosis. However, the heterozygotes have so far shown no evidence of variability in the loci of breaks, for some loci are regularly eliminated—that is, they appear in the hemizygous state—while others are always intact—that is, heterozygous or, by crossing-over, homozygous).

In this light, mechanical stresses might be thought to create additional breaks in the migratory chromosomes, to accelerate the loss of previously broken segments, or to alter their pairing ability. The concept of mechanical breakage of gametic chromosomes in transit is eminently plausible and deserves to be tested in other experimental materials. However, in view of the ambiguity of haploid analysis, nondisjunctional types should be looked for. If the hypothesis of fractional fertilization is correct, interrupted matings should lead to "diploids" that carry variable fragments of the Hfr genome, in contrast to the regular elimination types found from undisturbed matings. The documentation for these remarks may be found in another review [*J. Cellular Comp. Physiol.* Suppl. 2, 75 (1955)].

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Chromatographic Fractionation of Normal Adult Oxyhemoglobin

The chromatographic separation of different human carboxyhemoglobins by Prins and Huisman (*1*) and of carboxyhemoglobins of different species by Boardman and Partridge (*2*) has recently been reported. The application of column chromatography to oxyhemoglobin in our laboratory has shown that not only different types of hemoglobin can be separated but also that normal adult hemoglobin itself can be resolved into at least three components (*3*).

Indications of the nonhomogeneity of normal adult hemoglobin have appeared from time to time in the literature. Various techniques, including solubility (*4*), resistance to alkaline denaturation (*5*), and gasometric determinations (*6*), have been used for this purpose. Therefore, it seemed probable that the differences implied by these techniques could be great enough to permit separation of the distinct molecular species in a suitably sensitive chromatographic system. Preliminary

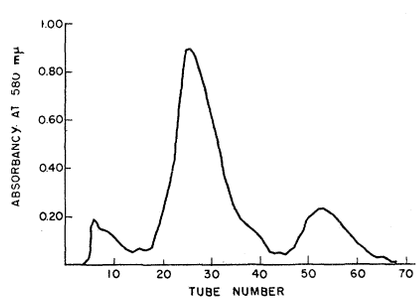

Fig. 1. Chromatogram of normal adult oxyhemoglobin.