Theor Appl Genet (1992) 84:640–642

Chiasma frequency in strains of mice selected for litter size and for high body weight

I. Gorlov [1], L. Schuler [2], L. Bunger [2], and P. Borodin [1]

[1] Institute of Cytology and Genetics, Siberian Branch of the Academy of Science of the USSR, Novosibirsk 630090, Russia
[2] Karl-Marx-University, Section Growth Production and Veterinary Science, Leipzig FRG

Received September 2, 1991; Accepted December 19, 1991
Communicated by E. J. Eisen

Summary. Chiasma frequency was measured in male mice of three outbred lines: FZt:DU (control); DU:6, selected for increased body weight; and DU:C, selected for high fertility. Chiasma frequency was seen to increase in the high body weight line, but decrease in the high fertility line. In both selected lines the intragroup variance in chiasma frequency increased while in DU:C the intracell variance was lower than in the control.

Key words: Mice – Recombination – Selection – Chiasmata

Introduction

Meiotic crossing-over is an effective source of genetic variation. Several studies have demonstrated changes in crossover frequency accompanying alterations in the genetic structure of the population. It has been shown that domestic animals have higher crossover frequency than their wild relatives (Burt and Bell 1987), as does *Drosophila* selected for tolerance to daily temperature fluctuations (Zhuchenko et al. 1983). The selection of *Drosophila* for behavioural changes also led to increased crossover frequency (Lobashev et al. 1973).

The aim of the study presented here was to analyse crossover frequency in three outbred lines of mice: FZt-:DU (control), DU:6 (selected for high body weight) and DU:C (selected for high fertility). We were able to show that both forms of selection are accompanied by changes in recombination.

Materials and methods

Selection for both high body weight and high fertility was carried out by mass selection from the outbred line FZt:DU. The effective population size of FZt:DU was 200 pairs, and that of each selected line, 80 pairs. Selection was carried out for 74 generations in DU:C and 59 generations in DU:6. The litter size at birth in DU:C rose from 10.35 to 17.73, while in the line selected for body weight, at age 42 days this had increased from 27.7 g in the control group to 55.9 g in DU:6 (Schuler et al. 1986; Bunger et al. 1989).

Since it has been shown that all crossing-overs in mouse meiosis leads to chiasma formation (Kanda and Kato 1980), a chiasma count for diakinesis cells can be used to estimate crossover frequency.

A standard method was used to prepare the meiotic chromosomes (Evans et al. 1964). The preparations were analysed using a light microscope at a magnification of 10×100. Six mice were analysed from each line using 28–75 diakinesis cells from each mouse. Only autosomes were analysed. Mean chiasma frequencies were compared using the t-test, and intragroup and intercell variance were assessed using the F-test (Zar 1984).

Results

Chiasma frequencies in the three lines are shown in Table 1. The mean number of chiasmata per cell in the control line FZt:DU is 21.72 ± 0.11. It is higher in line DU:6 [selected for high body weight ($t_d = 2.32$, $P < 0.05$)], but lower in line DU:C [selected for high fertility ($t_d = 3.46$, $P < 0.05$)]. The intragroup variance in chiasma number in the control line is 0.05. It is significantly lower in the line selected for high body weight [0.24 ($F_d = 4.4$, $P < 0.01$)] and in the line selected for litter size [0.19 ($F_d = 3.5$, $P < 0.01$). The intracell variance in number of chiasmata in the line selected for high body weight does not differ from that in the control, while in the line selected for high fertility it is significantly lower than in the control ($t_d = 2.64$, $P < 0.01$) (Table 1). (We excluded the value for male N 5 in the control line since it was anomalously different from that of the other males).

Correspondence to: I. Gorlov

Table 1. Chiasma frequency in selected and control lines of mice

Line	Number of animals	Mean number of cells analysed	Mean number of chiasmata and standard error	Intercell variance
FZt : DU	1	64	21.67±0.27	4.67
	2	72	21.89±0.25	4.49
	3	75	22.20±0.25	4.71
	4	75	21.36±0.22	3.65
	5	68	21.68±0.56	21.3
	6	40	21.53±0.27	3.92
Total		394	21.72±0.11	4.29±0.22
DU : 6	1	67	22.23±0.27	4.88
	2	46	22.26±0.29	3.88
	3	41	21.97±0.24	2.37
	4	48	23.13±0.30	4.33
	5	46	21.44±0.33	5.02
	6	28	22.77±0.40	4.33
Total		276	22.30±0.22	4.14±0.39
DU : C	1	61	20.37±0.20	2.43
	2	62	21.39±0.26	4.20
	3	51	20.79±0.23	2.69
	4	55	20.82±0.26	3.72
	5	57	20.73±0.18	1.85
	6	62	21.85±0.25	3.82
Total		348	20.96±0.19	3.13±0.38

Discussion

What causes changes in the recombination parameters in mice selected for increased body weight or fertility? It is known that the body weight of mice is controlled by a polygenic system (Schuler et al. 1986), and it is likely that the unselected population possesses chromosomes having various combinations of alleles influencing body weight. In the following discussion we shall use the sign "+" to label alleles that increase the size of the character being selected for and "−" to indicate alleles either having no effect or one that results in a decrease in size.

In the unselected population of mice the distribution of "+" and "−" alleles between and within chromosomes will be random. We can also assume that individuals in this population are highly heterozygous for alleles influencing body weight and fertility. Thus, there will be a high frequency of chromosomes of the type "+−+−+−+" or "−+−+−+−".

During selection of mice for body weight, a high crossover frequency is advantageous in so far as it favours the formation of chromosomes of type "++++". Later these chromosomes become fixed in the population. When all individuals in the selected line have the genotype "++++", a high crossover frequency will be neutral since recombined and unrecombined chromosomes will be indistinguishable.

In the line selected for high fertility, recombined individuals with the chromosome "++++" will already appear sufficiently often since fertility in this line is enhanced. High fertility in the DU:C line permits rare recombination events without an increased crossover frequency.

The hypothesis has already been proposed (Gorlov 1991) that one advantage of recombination is that it allows a population to preserve a balanced distribution of genotypes under the conditions of finite population size and genetic drift. According to this hypothesis an inverse relationship should be observed between the level of recombination and fertility. Populations with high fertility may, without the threat of extinction, carry a greater genetic load and have a lower recombination rate. In line DU:C, selected for high fertility, mortality is higher than in the control (Bunger et al. 1989), and it is probable that in this case an analogous mechanism leads to decreased crossover frequency.

A no less interesting question concerns the mechanism accounting for the increase in intragroup variance in both selected lines. The intragroup variance of any trait in an outbred line includes a genetic as well as an environmental component. However, when the same environments are maintained, the differences in intragroup variance between the three lines can be mainly due to the differences in the genetic components of the lines. We propose the following explanation. There are in the unselected mouse population two types of chromosomes that are affected by selection: types "+−+−+−+" and "++++". We do not consider chromosomes of type "−−−−" since selection acts against them. Different recombination strategies would be advantageous for the two types of chromosome. For type "+−+−+−+" it would be advantageous to have a high crossover frequency since this increases the probability of obtaining recombinant chromosomes of type "++++". Artificial selection will favour the fixation of alleles increasing the rate of recombination in such chromosomes. At the same time it would be advantageous for type "++++" chromosomes to have a low crossover frequency since this would favour preservation of the chromosome by preventing its disruption through crossing-over.

The mechanism suggested for the increase in intragroup variance of crossover frequency as a result of selection for a polygenic character assumes that crossover frequency can change independently in different chromosomes. A number of studies conducted in a variety of species indicates that crossing-over is independently controlled on different chromosomes (Elbinuma 1987; Kidwel 1972; Kramer and Lewis 1956).

Therefore, for different selected genotypes, different crossover frequencies might be advantageous: for type "++++" a low frequency, and for type "+−+−+−+" a high one. Directed selection of a polygenic character will therefore be accompanied by disruptive selection of crossover frequency. All this will take place within one

selected line. Accordingly, the intragroup variance of crossover frequency will rise.

After chromosomes of type "++++" have become established in the selected population and most individuals are homozygous for them, crossover frequency will become a neutral character, and after the cessation of selection it can return to the level found in the unselected population. In connection with this it is interesting to note that in line DU:C, which was selected for 15 more generations than DU:6, the intragroup variance of chiasma frequency was somewhat lower.

The lower intercell variance of chiasma frequency in DU:C, selected for increased fertility, is readily explained. It is known that in mice and many other species the chiasma frequency of bivalents has a lower limit: the bivalent must have at least one chiasma (Gorlov and Borodin 1991; Henderson 1963). Accordingly, the number of chiasmata in the karyotype also has a lower limit (19, i.e. one per autosome bivalent). A decrease in number of chiasmata in DU:C means that chiasma frequencies become concentrated as they approach the lower limit of 19, and as a result the intercell variance of chiasma frequency decreases.

Thus, a selection for polygenically controlled traits in mice increases intragroup variance in crossover frequency. The appearance of individuals with a higher or lower frequency of crossing-over in a selected line can change the level and spectrum of genetic variation and thus affect the selection process.

References

Bunger L, Herrendorfer G, Renne U, Schuler L (1989) Langzeitselektion – Demonstration eines Auswertungsmodells an 3 Beispielen. In: Proc 7th Symp Populationsgenet Grundlagen und ihre Umsetzung in die praktische Tierzucht. Red. H. Brandsh, Leipzig Univ. Ver. Leipzig, pp 102–117

Burt A, Bell G (1987) Mammalian chiasma frequency as a test of two theories of recombination. Nature 326:803–805

Elbinuma H (1987) Selective recombination system in *Bombyx mori*. 1. Chromosome specificity of the modification effect. Genetics 117:521–531

Evans EP, Breckon C, Ford C (1964) An air drying method for meiotic preparations from mammalian testes. Cytogenetics 3:289–294

Gorlov I (1991) The biological significance of gene recombination. Usp Sovrem Biol 111:532–546 (in Russian)

Gorlov I, Borodin P (1991) Chiasma distribution in normal karyotypes of mice. Genetika 27:247–251 (in Russian)

Henderson S (1963) Chiasma distribution at diplotene in a locust. Heredity 18:173–190

Kanda N, Kato H (1980) Analysis of crossing-over in mouse meiotic cells by BrdU labelling technique. Chromosoma 78:113–122

Kidwell M (1972) Genetic change of recombination value in *Drosophila melanogaster*. 1. Artificial selection for high and low recombination and some properties of recombination modifying genes. Genetics 70:419–432

Kramer H, Lewis E (1956) Normal inter-chromosomal crossover relationships in *Drosophila melanogaster*. J Hered 47:132–136

Lobashev ME, Ponomorenko VV, Polyanskaya GG, Tsapygina RI (1973) The role of the nervous system in regulating various genetic and cytological processes. Zh Evol Biokim Fiziol 9:398–405 (in Russian)

Schuler L, Bunger L, Rene U, Borodin P (1986) Diallele analysis of fertility characters in mice selected for reproductive and body-weight characteristics. Izv Sib Otd Akad Nauk SSSR 2:118–125 (in Russian)

Zar J (1984) Biostatistical analysis, 2nd edn. Prentice-Hall, Englewood Cliffs, N.J.

Zhuchenko AA, Korol AB, Kovtyukh LP, Tabak EP (1983) Increase in crossover frequency in a population selected for resistance to temperature fluctuations. Dokl Acad Nauk SSSR Ser Biol 273:721–725 (in Russian)