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'olychlorinated Biphenyls (Aroclors 1016 and 1242): Effects n Survival and Reproduction in Mink and Ferrets[1]

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Abstract. Diets that contained various levels of supplemental Aroclor® 1242 or Aroclor® 1016 were fed to mink and ferrets to investigate the chronic toxicity of these PCBs in two closely related species.

In mink, Aroclor 1242 was found to be more toxic than comparable or higher levels of Aroclor 1016. The Aroclor 1242 diets caused complete reproductive failure at levels as low as five ppm of the diet. Aroclor 1016 impaired reproduction less than Aroclor 1242. Although fewer females whelped and the four-week kit weights were less than the control animals, no outward signs of abnormalities beyond their smaller size were found in the kits whelped and nursed by dams fed Aroclor 1016.

Ferrets were more resistant to the effects of either PCB mixture than were the mink, as noted by the lower mortality rate on the Aroclor 1242 diet and the almost normal level of reproduction on the Aroclor 1016 diet. Feeding Aroclor 1242 at 20 ppm resulted in complete reproductive failure, but was not fatal to adult ferrets. This finding is in sharp contrast to the 100% mortality of adult mink fed the same level. Although the chlorine content is similar in both compounds, Aroclor 1242 has a higher percentage of molecules with five or more chlorines per biphenyl.[2] This difference in higher substituted biphenyl isomer content and/or the reduced levels of contaminants in the Aroclor 1016 mixture may be of major importance in evaluating the toxicity of these compounds.

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As a rule, the last two numbers of the four-digit Aroclor number indicates the percentage of hlorine in the mixture. One exception is Aroclor 1016, a PCB mixture, which contains 41% hlorine and was developed to replace Aroclor 1242. The penta-, hexa-, and heptachlorobiphenyl ontent of Aroclor 1016 is 10% of that in Aroclor 1242 (Hutzinger *et al.* 1974, Matthews *et al.* 978). Aroclor is trade name for PCBs formerly produced by Monsanto Co., St. Louis MO

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03/01/2001 17:44 5054243202 JILL PODOLSKY, EHA PAGE 01

Prolonged oral consumption studies of various polychlorinated biphenyls (PCBs) have been conducted in mice (Kimbrough and Linder 1974), rats (Wassermann *et al.* 1973), subhuman primates (Allen and Norback 1976), chicks (Rehfeld *et al.* 1971), and mink (Aulerich and Ringer 1977). Of these species, the mink ranks among the most sensitive, particularly with regards to embryotoxicity (Aulerich *et al.* 1973, Aulerich and Ringer 1977).

The purpose of this study was to determine the effects of two polychlorinated biphenyl mixtures (Aroclors 1242 and 1016) on growth and reproduction in mink (*Mustela vison*) and ferrets (*Mustela putorius furo*). Aroclor 1016 and Aroclor 1242 contain similar amounts of chlorine by weight (41.3% vs. 42%), but vary in their respective percentages of biphenyls with five or more chlorines per molecule. Aroclor 1016 has approximately 1% of biphenyl with more than four chlorines per molecule, while Aroclor 1242 contains 9% biphenyl with five or more chlorines (Goldstein *et al.* 1975). The Aroclor 1016 mixture also contains lower levels of contaminants such as chlorinated dibenzofurans (Bowes *et al.* 1975) and chlorinated dibenzodioxins than the more highly chlorinated PCB mixtures.

Methods and Materials

One hundred five pastel mink were randomly divided into five treatment groups and a control group. Each treatment group consisted of twelve females and three males, while the control group contained twenty-four females and six males. The mink were fed a basal diet[3] supplemented with either 0 ppm (control), 5 ppm, 10 ppm, 20 ppm, or 40 ppm Aroclor 1242, or 20 ppm Aroclor 1016. Forty-five ferrets were randomly assigned to three groups each containing twelve females and three males. The ferrets were fed the basal unsupplemented diet (control), 20 ppm Aroclor 1242, or 20 ppm Aroclor 1016. Diets were prepared by dissolving the desired quantity of PCB in acetone and mixing the solution with ground commercial mink cereal. The acetone was then evaporated off and the cereal-compound premix mixed with the other dietary ingredients to produce a diet that contained the desired amount of PCB.

The mink were vaccinated as kits against canine distemper, botulism, and virus enteritis. The ferrets were immunized against canine distemper.

The experiment was started November 1, 1977 and was continued through July 5, 1978. Routine ranch procedures were followed in the feeding, care, and breeding of all animals. Females were mated to males within their respective dietary groups. The female ferrets were mated beginning with their first cycle in April. Any females that recycled were remated up to three times. The female mink were mated in March. Each female mink was given an opportunity to remate either the day after the original mating or eight days later. All matings were verified by the presence of motile spermatozoa in a vaginal smear taken after copulation. The mated females were checked daily for young during the whelping period. Kits were counted and weighed on the day of birth and at four weeks of age.

Treatment differences were detected by unpaired "t"-test for the difference between two means.

Results

Aroclor 1242 produced 100% mortality in all adult mink that were fed diets at the 20 ppm and 40 ppm levels (Table 1). At 10 ppm, a mortality rate of 66.7%

[3]The basal diet consisted of 27% whole chicken, 23% commercial mink cereal, 17% ocean fish scrap mix, 9% beef tripe, 8% cooked eggs, 5% beef liver, 5% beef trimmings, 5% beef lungs, and 1% powdered milk

ıble 1. Mortality of adult mink and ferrets and survival time of mink fed Aroclor 1242 that died ıring a 247-day study

etary atment	Mortality males No. died/ No. total	%	Mortality females No. died/ No. total	%	Survival time of mink that died (days ± S.E.) Males	Females
nk						
ppm PCB	0/6	0.0	3/24	12.5	—	75 ± 19.2 (38–102)
ppm Aroclor 1242	0/3	0.0	1/12	8.3	—	151
ppm Aroclor 1242	2/3	66.7	8/12	66.7	156 ± 25.3 (123–189)[a]	171 ± 6.6 (142–190)
ppm Aroclor 1242	3/3	100.0	12/12	100.0	170 ± 14.1 (147–192)	153 ± 5.8 (133–190)
ppm Aroclor 1242	3/3	100.0	12/12	100.0	120 ± 12.0 (96–132)	122 ± 5.3 (89–138)
ppm Aroclor 1016	0/3	0.0	3/12	25.0	—	92 ± 4.9 (86–102)
rrets						
ppm PCB	0/3	0.0	0/12	0.0	—	—
ppm Aroclor 1242	0/3	0.0	0/12	0.0	—	—
ppm Aroclor 1016	0/3	0.0	1/12	8.3[b]	—	—

ange in days
breech presentation, female died due to complications

curred in males and females, while the 5 ppm diet was lethal only to one nale. No mortality was noted in male mink fed the control, 5 ppm Aroclor 42, or 20 ppm Aroclor 1016 diets. Female mink fed the 20 ppm Aroclor 1016 t showed a greater number of deaths than the control animals (25% vs. 12.5%), t a much lower mortality than those fed the same level (20 ppm) of Aroclor 42 (25% vs. 100%). As shown in Table 1, the mean survival time of mink fed oclor 1242 was, in general, inversely related to the level of dietary PCB.

All mink that died during the study were necropsied and observed for gross normalities. Necropsy revealed emaciation characterized by an almost com- te absence of body fat in the mink fed Aroclor 1016 or 1242 diets. Gastric ers, as described by Aulerich *et al.* (1973), were noted in some mink fed the oclor 1242 diets. Control mink that died did not exhibit this extreme emacia- n or incidence of gastric ulcers. Prior to death, the treated animals showed orexia, weakness, and often lethargy.

No mortality occurred in the ferrets, with the exception of a single female t was fed 20 ppm Aroclor 1016. This death was due to complications arising m a breech presentation at whelping, and was not attributed directly to the B treatment.

Reproduction was dramatically reduced in mink fed either of the PCBs able 2). Feeding Aroclor 1242 resulted in complete reproductive failure in se animals that survived long enough to be bred. The 40 ppm diet caused ath in all animals prior to the breeding season (March). Eight females fed the ppm Aroclor 1242 diet survived long enough to be mated, but died prior to whelping period (late April to early May). Animals fed the 5 ppm and 10

03/01/2001 17:44 5054243202 JILL PODOLSKY, EHA PAGE 03

Table 2. Effect of PCBs on reproductive performance of mink and ferrets

	No. ♀ whelped/ No. × mated	Whelped (%)	Average gestation (days)	No. whelped		Alive at birth (%)	Live kits/♀	
				Alive	Dead		Mated	Whelped
Mink								
0 ppm PCB	16/21	76.2	50.2	79	14	84.9[a]	3.8[a]	4.9[a]
5 ppm Aroclor 1242	0/12	0.0	—	—	—	—	—	—
10 ppm Aroclor 1242	0/11	0.0	—	—	—	—	—	—
20 ppm Aroclor 1242	0/8	0.0	—	—	—	—	—	—
40 ppm Aroclor 1242	0/6	0.0	—	—	—	—	—	—
20 ppm Aroclor 1016	4/9	44.4	51.3	25	5	83.3[a]	2.7[a]	6.3[a]
Ferrets								
0 ppm PCB	12/12	100.0	41.0	118	5	95.9[b]	9.8[b]	9.8[b]
20 ppm Aroclor 1242	0/12	0.0	—	—	—	—	—	—
20 ppm Aroclor 1016	10/12[a]	83.3	41.2	87	4	95.6[b]	7.3[b]	8.7[b]

[1] Means within same column for each species with same superscript are not significantly different ($P < 0.05$)
[a] Does not include female that died during breech presentation

ppm diets also failed to reproduce. The twenty-three females mated in these two groups (12 females fed 5 ppm and 11 fed 10 ppm) failed to demonstrate any outward signs of pregnancy prior to death or during the gestation period. Aroclor 1016 also reduced, but did not completely eliminate reproduction. Four of the nine mated females produced kits. The relative percentage of kits born alive was not affected by the reduced number of females that whelped.

The ferrets that received the control diet showed a whelping rate of 100%. The percentage of kits born alive was 95.9, with an average of 9.8 kits per female. Ferrets fed the Aroclor 1242 diet did not whelp. The females cycled, as evidenced by vulvar swelling, several times during the breeding season of March to August (Ryland and Gorham 1978). Each was mated during three separate cycles but failed to exhibit outward signs of pregnancy. However, implantation sites were observed in two females when the study was terminated and the animals necropsied. As shown in Table 2, the reproductive performance of the female ferrets fed Aroclor 1016 was not significantly different from that of the control females.

The birth weight of mink kits whelped by dams fed Aroclor 1016 averaged numerically less than that of kits whelped by dams fed the control diet (Table 3). This difference, however, was not significant ($P < 0.05$). Four-week body weights were significantly lower for the kits nursed by dams fed Aroclor 1016. There was also a significant ($P < 0.01$) reduction in the biomass (average kit body weight gain between birth and four weeks of age × the average number of kits raised per lactating female) produced by female mink fed Aroclor 1016 when compared to control females (Table 3). The lactating control females produced 2.4 times the biomass of the lactating females fed Aroclor 1016. Mortality between birth and four weeks of age was 2.3 times greater in mink kits produced and nursed by females that consumed Aroclor 1016 than in the control diet (56.0% vs. 24.1%).

Reproductive parameters, kit growth, and adult and kit mortality were not significantly affected in the ferrets fed the Aroclor 1016 diet.

Table 3. Average body weights and mortality of kits whelped and nursed by female mink and ferrets fed PCBs

	Kits						
	At birth		At 4 weeks				
	No. alive	Body wt. (g ± S.E.)	No. alive	Body wt. (g ± S.E.)	Avg. no. kits/ lactating ♀	Biomass[1] (g)	Mortality to 4 wks. (%)
Mink							
0 ppm PCB	79	9.0 ± 0.20[a][2]	60	127.7 ± 2.33[a]	4.62[a]	548.4[a]	24.1
5 ppm Aroclor 1242	0*						
10 ppm Aroclor 1242	0*						
20 ppm Aroclor 1242	0*						
40 ppm Aroclor 1242	0†						
20 ppm Aroclor 1016	25	8.4 ± 0.25[a]	11	91.6 ± 9.94[c]	2.75[c]	228.8[c]	56.0
Ferrets							
0 ppm PCB	118	8.1 ± 0.13[b]	108	136.6 ± 3.05[b]	9.00[b]	1156.5[b]	8.5
20 ppm Aroclor 1242	0*						
20 ppm Aroclor 1016	87	8.5 ± 0.16[b]	77	142.9 ± 2.11[b]	7.70[b]	1034.9[b]	11.5

* All females failed to whelp

† All females died prior to mating

[1] Biomass = average kit body weight gain between birth and 4 weeks of age × the average number of kits per lactating female

[2] Means within same column for each species with same superscript are not significantly different ($P < 0.05$)

03/01/2001 17:44 5054243202 JILL PODOLSKY, EHA PAGE 05

Discussion

The results of this study indicate that mink are better able to tolerate Aroclor 1016 than Aroclor 1242. Diets supplemented with 20 ppm of Aroclor 1016 caused moderate reproductive complications in mink, while dietary levels of only 5 ppm of Aroclor 1242 resulted in complete reproductive failure. The adverse effects on reproduction caused by PCBs do not appear to be due to an effect on spermatogenesis. PCB-treated male mink have had acceptable levels of reproduction when mated to untreated females (Aulerich and Ringer 1977). Based on previous observations, the effects on reproduction do not appear to be due to inhibition of oogenesis, ovulation, or implantation; since fetuses were seen in various stages of resorption. At dietary levels greater than 5 ppm, Aroclor 1242 resulted in considerable adult mortality in addition to reproductive failure. The ability of mink to reproduce when fed 20 ppm Aroclor 1016 in the diet for six months is in contrast to the results reported for other PCB mixtures (Platonow and Karstad 1973; Aulerich and Ringer 1977).

In this study, mortality was limited to three female mink on the diets supplemented with 20 ppm of Aroclor 1016; whereas, a comparable level of Aroclor 1242 resulted in 100% mortality of both male and female mink. The 71% adult mortality reported by Aulerich and Ringer (1977) in mink fed 10 ppm Aroclor 1254 for 10 months is similar to the 67% mortality noted in the mink that received 10 ppm dietary Aroclor 1242 for nine months in this study.

There was no difference in mortality rates between male and female mink fed diets supplemented with 10 ppm, 20 ppm, or 40 ppm of Aroclor 1242. However, in mink fed the 5 ppm Aroclor 1242 or the 20 ppm Aroclor 1016 diets, deaths were limited to female mink. Male mink have also been shown to survive longer than female mink when fed low levels (0.64-3.57 ppm) of Aroclor 1254 (Platonow and Karstad 1973).

If it is assumed that female mink consume 150 g of feed per day (Schaible 1970), the mean total consumption of Aroclor 1242 by the females that died (Table 1) while being fed diets that contained 5, 10, 20, and 40 ppm of this PCB was 113, 257, 460, and 729 mg, respectively. Using this assumed feed consumption and a mean body weight of 800 g, an LD_{50} for the females fed 10, 20, and 40 ppm Aroclor 1242 can be calculated as follows: LD_{50} = feed consumed per day × PCB concentration in the diet × mean days survived until 50 percent mortality ÷ body weight. Based on this formula, the calculated LD_{50} for females fed 10, 20, and 40 ppm Aroclor 1242 was 315, 521, and 833 mg/kg, respectively. These increasing LD_{50} values with respect to higher dietary concentrations may indicate differential absorption of the PCB mixture.

A comparison of the relative toxicity of Aroclors 1242 and 1016 with Aroclor 1254, a prevalent PCB mixture in the environment extremely toxic to mink (Aulerich and Ringer 1977), can be made from the data presented in Table 4. At levels of ingestion of 5 and 10 ppm, mortality and reproduction results were similar for mink fed Aroclors 1242 and 1254. However, at a lower dietary level of 2 ppm, Aroclor 1254 impaired reproduction while Aroclor 1242 did not have an adverse effect.

An estimated LC_{50} (dietary concentration lethal to 50 percent of the mink) can be calculated for Aroclors 1242 and 1254 from the data presented in Table 4. Using the procedure of Litchfield and Wilcoxon (1949) the LC_{50} for Aroclor

Table 4. Summary of mortality and reproduction in mink fed various levels of Aroclors 1254, 1242, and 1016

Treatment level (ppm)	Period fed (days)	Mortality (no. dead/no. total)	Reproduction (kits/♀)
Aroclor 1254[a]			
0	280	1/7	5.0
0	297	0/8	4.1
2	297	1/8	0.3
5	280	2/7	0.0
10	280	5/7	0.0
Aroclor 1242			
0	247	3/30	4.9
2[a]	297	1/8	5.6
5	247	1/15	0.0
10	247	10/15	0.0
20	192[b]	15/15	0.0
40	138[c]	15/15	0.0
Aroclor 1016			
0	247	3/30	4.9
2[a]	297	0/8	4.5
20	247	3/15	6.3

[a] Data from Aulerich and Ringer, 1977
[b] All mink died within 192 days on diet
[c] All mink died within 138 days on diet; no females survived to whelping

1242 fed to mink is 8.6 mg per kg diet when fed for 247 days. The slope of the dose-effect curve is 0.699. For Aroclor 1254 the LC_{50} is 6.65 ppm when fed for 280 to 297 days. The slope of this line is 2.627. Therefore, Aroclor 1242 has a greater margin of safety than Aroclor 1254 for mink.

Although the effects of feeding Aroclor 1016 to mink were not as dramatic as those that occurred from the feeding of Aroclor 1242, some detrimental effects were observed. These included increased mortality among adult female mink in addition to reduced four-week body weights of kits. Higher kit mortality between birth and four weeks of age was also noted.

The growth rate of the nursing kits was expressed as the average biomass (Table 3) to account for the fact that kits raised by females with large litters may not receive as much milk per kit as those raised by females with smaller litters and, therefore, would weigh less at four weeks of age. Since almost all of the kit's weight-gain up to four weeks of age is from the nourishment provided by the dam's milk, the reduced four-week weights and increased mortality of kits nursed by dams fed Aroclor 1016 might be attributed to dam effects. PCBs have been shown to be excreted in milk (Platonow *et al.* 1971) and this may account for the poor growth and increased mortality of these mink kits. There may also be a reduction in the quantity of milk produced by the PCB-fed females, putting further stress on the growing kit. Long-term, low-level feeding of PCBs has also been found to reduce weight gains and feed efficiency in growing swine and sheep (Hansen *et al.* 1976).

The ferrets were not as severely affected by either PCB mixture as were

03/01/2001 17:44 5054243202 JILL PODOLSKY, EHA PAGE 07

the mink despite the fact that food consumption is comparable between the two species. Mortality of adult ferrets was nonexistent (except for the breech presentation). Reproduction was prevented in the ferrets fed 20 ppm Aroclor 1242, a level lethal to 100% of the adult mink.

The difference in toxicity found between Aroclor 1016 and other PCB mixtures may be due to limited absorption of Aroclor 1016, a higher excretion rate of 1016, the removal of contaminants such as chlorinated dibenzofurans (Bowes *et al.* 1975) and chlorinated dibenzodioxins (Porter and Burke 1971) from Aroclor 1016, or because Aroclor 1016 is metabolized to a greater extent. The degradation of the lower chlorinated biphenyls has been shown to be much more rapid than for the more highly substituted biphenyls (Hutzinger *et al.* 1974, Tucker *et al.* 1975). The ability of mink to metabolize and excrete PCBs may be dependent upon the percentage of the higher chlorinated biphenyls, as well as the overall percentage of chlorination of the PCB mixture.

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03/01/2001 17:44 5054243202 JILL PODOLSKY, EHA PAGE 09