Transfer of DDT used in malaria control to infants via breast milk

H. Bouwman,[1] P.J. Becker,[2] R.M. Cooppan,[3] & A.J. Reinecke[4]

The transfer of p,p′*-DDT (1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane) and its metabolites to infants via breast-feeding was studied in an area of KwaZulu, South Africa, where DDT is used to interrupt malaria transmission. Samples of whole blood were collected from 23 infants, together with samples of breast milk from their respective mothers. The mean ΣDDT (total DDT) in the whole blood was 127.03 μg.l^{-1} and that in the breast milk, 15.06 mg.kg^{-1} (milk fat). The % DDT (% DDT of ΣDDT) was significantly higher in the infant blood than in the breast milk (P <0.05).*

A multiplicative regression analysis indicated that ΣDDT increased significantly (P <0.01) in infant whole blood with infant age. Multiple regression showed that 70.0% of the variation in ΣDDT was due to the variation in parity of the mother, age of the infant, and the ΣDDT in breast milk. These variables accounted also for 76.3% of the variation in p,p′-DDE but only for 38.2% of that in p,p′-DDT. Organochlorines were therefore largely transferred to the infant from the mother, with DDT in the environment playing a secondary role.

Introduction

p,p′-DDT (1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane) is used to interrupt malaria transmission in the malaria-endemic areas of KwaZulu, South Africa (*1*). For this purpose, it is applied annually on the inner walls of all dwellings at a coverage of 2g /m^2. The levels of DDT and its metabolites in the breast milk of lactating mothers significantly exceed (*2*) the estimated acceptable daily intake (ADI) for total DDT (ΣDDT) of 0.02 mg.kg^{-1}. day^{-1} (*3*). The mean ΣDDT (*p,p′*-DDT + *p,p′*-DDE + *p,p′*-DDD)[a, b] in the breast milk of 129 mothers was 15.83 mg.kg^{-1} (milk fat: DDT = 6.77 mg.kg^{-1}; DDD = 0.3 mg.kg^{-1}; and DDE = 6.2 mg.kg^{-1}).

In a survey on human exposure to selected organochlorine compounds, Slorach & Vaz reported the mean national levels of DDT and DDE in milk from various countries (*4*). The highest median levels in milk fat were from China (DDE = 4.4 mg.kg^{-1} and DDT = 1.8 mg.kg^{-1}) and India (DDE = 4.8 mg.kg^{-1} and DDT = 4.4 mg.kg^{-1}), where DDT is still used in agriculture and for vector control. The samples were taken from mothers who lived in urban areas and who were nursing their first or second child.

First-borns in KwaZulu were exposed to significantly higher levels of ΣDDT (24.82 mg.kg^{-1} in milk fat) than were subsequent infants (12.21 mg.kg^{-1} in milk fat) (*5*). Because of the practice of breast-feeding for as long as possible (2 years or longer), large amounts of DDT can be transferred to the infants. The proportion of DDT (% DDT of ΣDDT) in breast milk, on the other hand, increased significantly (*P* <0.05) with parity, from a mean of 34.5% for primiparous mothers to means of 46.4%, 50.9%, 50.6%, and 47.3% for mothers who were breast-feeding their second, third, fourth, and fifth to tenth child combined, respectively. It was hypothesized that this increase was due to the uptake and faster elimination of DDT via milk rather than to the uptake and endogenous formation of DDE in the mother (*5*).

Infants cannot be considered to be recipients of xenobiotics in the same way as older children or adults (*6, 7*), because the rate at which infants accumulate DDT together with associated factors (such as breast-feeding, metabolism and immunological status) change with age. Rogan et al., in the only study that has examined the effects of DDE in breast milk on infants, found a significant increase in the

[1] Senior Lecturer, Department of Zoology, Potchefstroom University for Christian Higher Education, Private Bag X6001, 2520 Potchefstroom, South Africa. Requests for reprints should be sent to this author.

[2] Specialist Scientist, Institute for Biostatistics, Medical Research Council, 0001 Pretoria, South Africa.

[3] Chief Senior Medical Research Officer, Research Institute for Diseases in a Tropical Environment, Medical Research Council, Congella, South Africa.

[4] Professor, Department of Zoology, Potchefstroom University for Christian Higher Education Potchefstroom, South Africa.

[a] DDE = 1,1-dichloro-2,2-bis(4-chlorophenyl)ethylene.

[b] DDD = 1,1-dichloro-2,2-bis(4-chlorophenyl)ethane.

Reprint No. **5272**

number of infants showing hyporeflexia that was associated with an increase in the DDE concentration in breast milk (*8*). These effects became apparent at DDE levels of ≥4 $mg.kg^{-1}$ in milk fat. There is therefore still a lack of understanding about the levels and effects of DDT on infants. Since in developing countries mothers and infants are exposed to DDT via malaria control and agricultural activities, the levels and associated factors need to be determined to assess risk. The aims of the present study were therefore as follows: to determine the levels of DDT and its metabolites in blood from infants who had been exposed to high levels of DDT in breast milk; and to design statistical models from the results.

Materials and methods

The study design and the methods used were approved by the Ethical Committee of the Research Institute for Diseases in a Tropical Environment. For the purpose of the study infants were defined as children aged 0–2 years. Corresponding milk and blood samples were collected at the Mseleni Hospital, northern KwaZulu, during 1987. The mothers who attend routine well-baby clinics at Mseleni Hospital live in an area where DDT is used for malaria control. Mseleni is situated on the shore of Lake Sibaya and is removed from the major routes of population migration. During a pilot study it was found that migrants from Mozambique, where hardly any malaria control is practised, had very low levels of DDT (*2, 5*). Dwellings in KwaZulu are usually constructed of mud, branches, and thatch. Homesteads consist of three to seven such structures and house 4–22 people. The major source of income is from migrant labour in mines or on farms. The diet consists of staples such as maize and rice together with fish and meat from goats, chickens or cattle. This is supplemented by collecting wild fruits, nuts, and roots.

Northern KwaZulu is a malaria-endemic area where DDT has been applied only for malaria control. No agricultural use of this pesticide has been recorded, and DDT has been banned for this purpose in South Africa since 1976 (*2*).

Sample collection and analysis

All mothers who attended the hospital on a routine baby-clinic day were approached. Questionnaires were filled out for all mothers who participated, and information on maternal and infant age, parity, duration of residence in DDT-sprayed dwellings, and maternal occupation was obtained.

Mothers were supplied with a 100-ml glass beaker and asked to express manually about 10 ml of milk, which was transferred immediately to 10-ml blood-collecting tubes and capped. The tubes were stored on ice until they were frozen on the same day.

Samples of blood were only taken from infants whose mothers produced enough milk. The big toe of the infant was cleaned with Hibitane and allowed to dry; a toe prick with a sterile lancet was then made and a capillary tube[c] (44.7 µl) was tilted at a slightly upward angle and filled by capillary action (a downward angle resulted in air bubbles being drawn in). The capillary tube was then placed in a 3-ml test-tube containing 2 ml of doubly distilled water. The test-tube was capped and shaken vigorously to dislodge and lyse the blood from the capillary tube. The test-tubes were also stored on ice until they were frozen on the same day. The milk and blood samples were then analysed as described previously (*9, 10*). The results are reported on a milk-fat basis to allow comparison with those from other studies.

Results

The socioeconomic circumstances of the study group were such that no activity (e.g., employment in a pesticide factory) or location (e.g., near an intensive farm that used DDT) could have caused additional exposure to DDT, other than from background levels or from malaria control activities. There were also no obvious factors that would have resulted in a major variation in exposure to DDT for either the mother or infant.

Only three of the mothers who were approached refused to allow a blood sample to be taken from their infants. A summary of the statistics on the characteristics of the 23 infants and mothers is presented in Tables 1 and 2. Maternal age was difficult to establish, as in many cases it was not known; an estimated age was therefore used. The same was true for the age of the infants, but here more accurate inference was possible.

The analytical technique employed was not sensitive enough to detect DDD in the infant blood. The proportion of DDD in the breast milk, however, was less than 3% and its contribution could therefore be ignored. DDE and DDT were detected in all blood samples (Table 1); marked variations in the levels of ΣDDT, DDT and DDE resulted in large standard deviations. The maximum ΣDDT concentration was 316.5 $\mu g.l^{-1}$. Infant age and parity did not differ

[c] Coulter Pipets, Coulter Diagnostics, Hialeah, FL, USA.

Table 1: **Summary of statistics for all variables relating to the infants tested in the study (in each column the data are for 23 infants)**

	Concentration in whole blood ($\mu g.l^{-1}$):					
	DDE	DDT	ΣDDT	%DDT[a]	Infant age (days)	Parity
Mean	67.12 (52.92)[b]	59.91 (30.17)	127.03 (70.84)	50.88 (16.16)	252.4 (144.99)	3.17 (1.85)
Median	49.7	58.10	114.2	49.37	240	3
Minimum	5.6	16.9	29.4	22.15	5	1
Maximum	218.4	135.3	316.5	80.95	540	7

[a] % DDT = % DDT of ΣDDT.
[b] Figures in parentheses are the standard deviations.

Table 2: **Summary of statistics for all variables relating to the mothers of the infants tested in the study (in each column the data are for 23 mothers)**

	Concentration in whole milk ($\mu g.l^{-1}$):				Concentration in milk fat ($mg.kg^{-1}$)						
	DDE	DDD	DDT	ΣDDT	DDE	DDD	DDT	ΣDDT	%DDT	Maternal age (years)	Milk fat (%)
Mean	297.0	13.60	222.9	535.1	8.87	0.44	6.74	15.06	45.40	25.83	3.50
	(345/1)[a]	(10.34)	(184.7)	(519.9)	(7.81)	(0.36)	(4.31)	(11.08)	(5.97)	(5.53)	(1.58)
Median	201.5	9.89	200.9	427.1	7	0.34	5.9	13.1	45.06	25	3.15
Minimum	67.1	1.05	35.6	144.1	1.9	0.02	1.22	3.1	35.24	17	1.43
Maximum	1758.8	43.7	967.9	2743.4	36.9	1.6	20.3	57.6	57.28	35	6.29

[a] Figures in parentheses are percentages.

significantly ($P > 0.05$) from those found in three previous surveys that examined serial changes in the levels of DDT in breast milk (*3*).

DDE, DDD, and DDT were detected in all milk samples (Table 2); marked variations were again in evidence. The maximum value of 57.6 $mg.kg^{-1}$ for ΣDDT in milk fat should be noted. The concentrations (but not the % DDT) were skewed, and logarithmic transformations were used in subsequent analyses.

A significant multiplicative relationship (ln (% DDT in infant blood) = –4.1 + 2.1x(ln %DDT in breast milk)), coefficient of determination = 60.6%, was found between the % DDT in infant blood and the % DDT in the corresponding sample of breast milk ($P < 0.001$; Fig. 1). The % DDT in milk (corrected for DDD by subtraction) and the % DDT in infant blood were compared using a paired Student's *t*-test. The proportion of DDT was 5.35% higher in infant blood than in breast milk, which was significant ($P < 0.05$).

The coefficient of determination from the linear regression of ΣDDT on infant age (days) was 30.3% (ΣDDT = 59.18 + 0.268x(infant age); $P < 0.01$). The relevant statistics for the multiplicative regression, which exhibited an improved coefficient of determination of 44.95%, are shown in Fig. 2.

Multiple regression with stepwise variable selection was used to model the levels of ΣDDT, DDT and DDE in infant blood. Variables such as parity, infant age, maternal age and percentage milk fat were introduced. The best model for describing ΣDDT is illustrated in Fig. 3. Maternal age in combination with any of the other variables reduced the accuracy of the model. The best models for DDE and DDT are shown in Fig. 4 and 5, respectively.

Discussion

The levels of DDT and its metabolites in whole blood differ from those in plasma or serum, in that 75% of the ΣDDT occurs in the plasma fraction (*11*). Morgan et al. reported that less than 18% of the DDT and DDE was associated with red blood cells (*12*). If we assume the same relationship for infant blood and a haematocrit of 50%, the levels found should at least be doubled for comparison with

Fig. 1. **Multiplicative regression of percentage DDT in samples of infant's whole blood against percentage DDT in the corresponding samples of mother's breast milk.** CD = coefficient of determination.

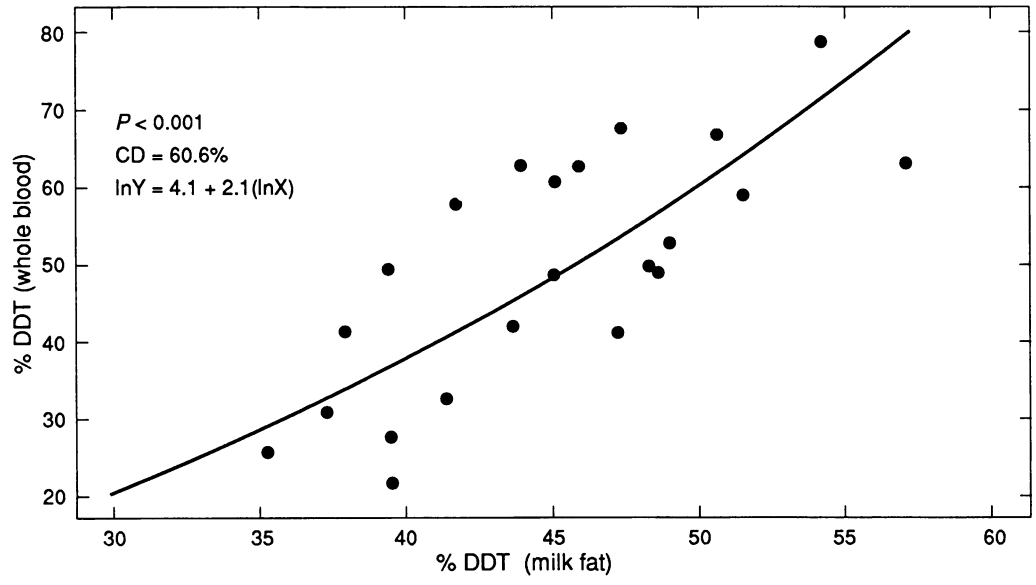


Fig. 2. **Multiplicative regression of ΣDDT in samples of infant's whole blood against infant age.** CD = coefficient of determination.

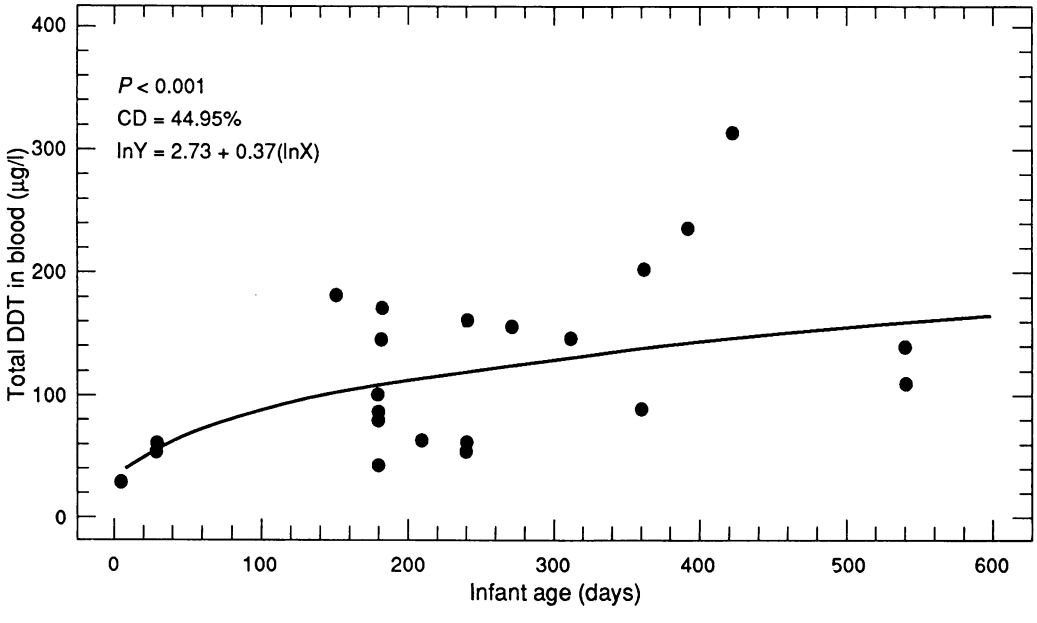


Fig. 3. **Multiple regression model of ΣDDT in samples of infant's whole blood.** PAR = parity; IA = infant age; CD = coefficient of determination.

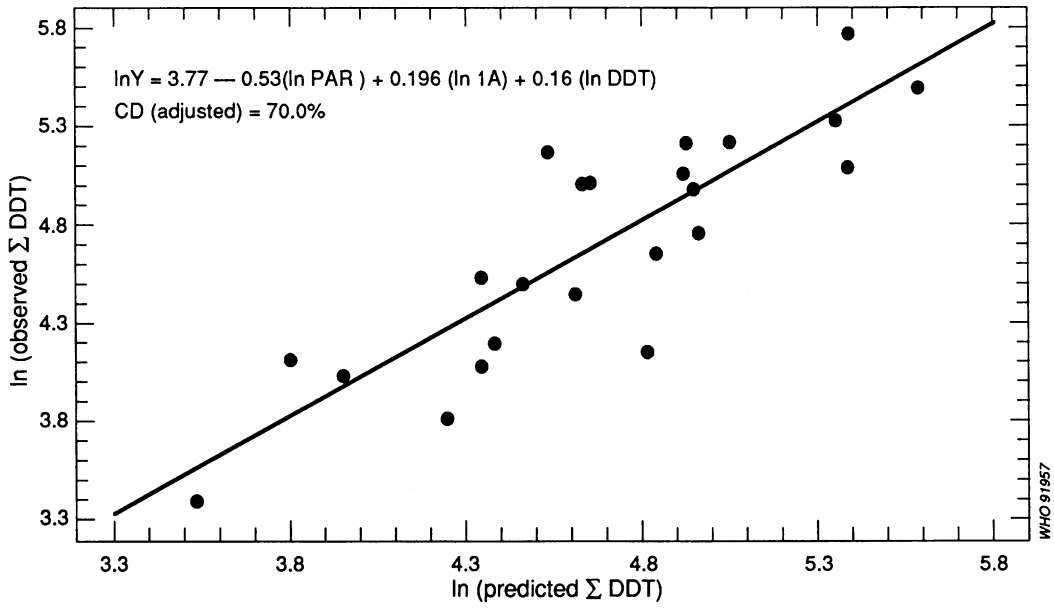


Fig. 4. **Multiple regression model of DDE in samples of infant's whole blood.** PAR = parity; IA = infant age; CD = coefficient of determination.

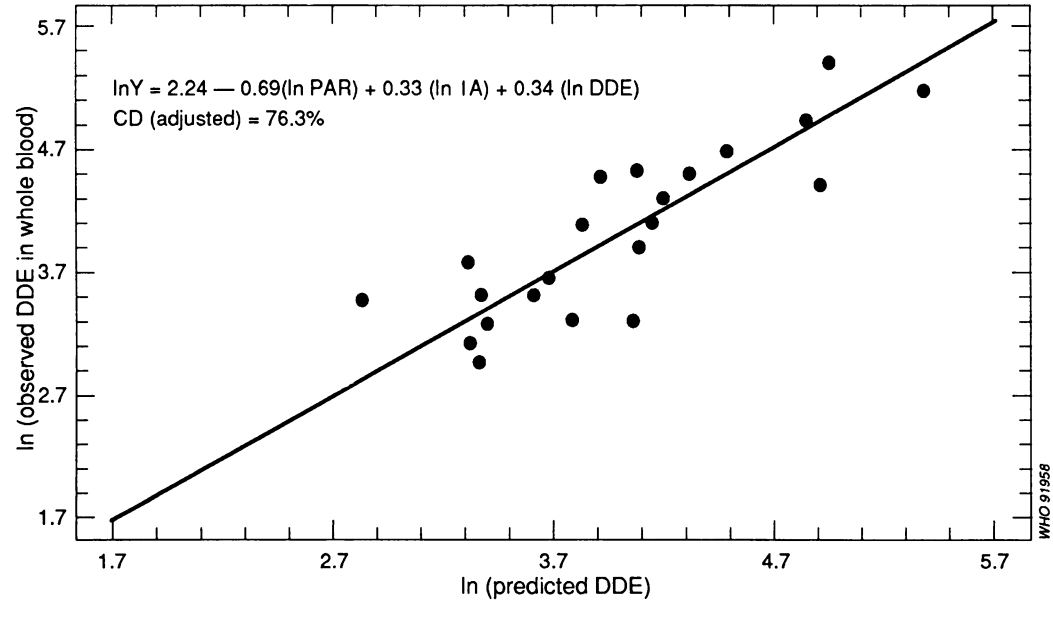
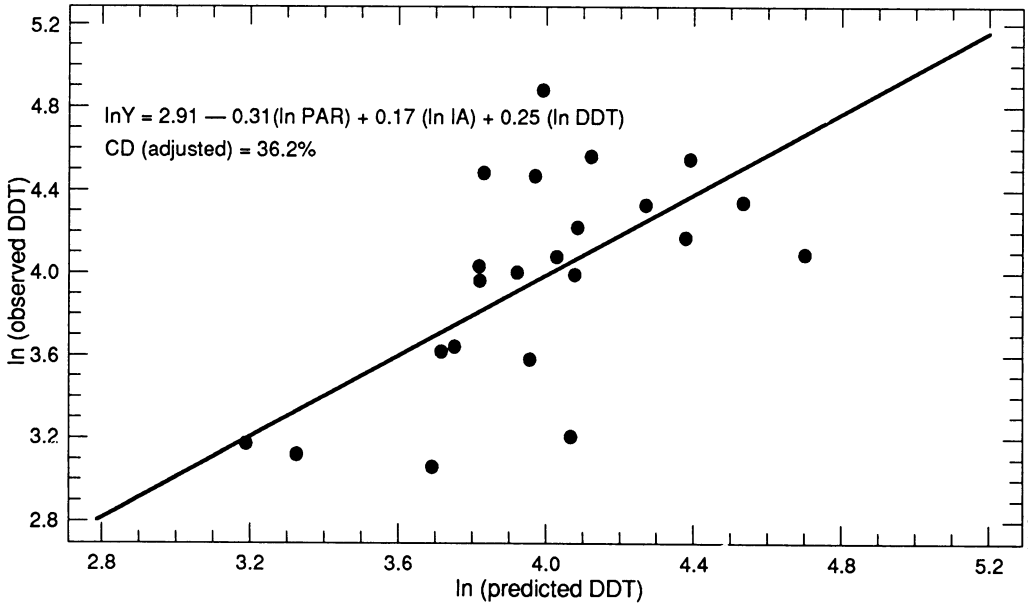


Fig. 5. **Multiple regression model of DDT in samples of infant's whole blood.** PAR = parity; IA = infant age; CD = coefficient of determination.



serum data. This gives a mean serum level for the infants of 254 $\mu g.l^{-1}$ for ΣDDT, which exceeds that found for the general population in the study area (140.9 $\mu g.l^{-1}$; $n = 71$) (*13*). The mean serum level for 3–9-year-olds ($n = 24$) in this population was 168.6 $\mu g.l^{-1}$ for ΣDDT (*13*). Kreiss et al. found a mean ΣDDT level in serum of 159.4 $\mu g.l^{-1}$ for a population with exceptional exposure to DDT (through consumption of contaminated fish and water) (*14*); the serum level for 1–9-month-olds in the same population was ±30 $\mu g.l^{-1}$ for ΣDDT (determined graphically), and increased with age. Breast-fed children had higher levels of ΣDDT than those who were not breast-fed (*14*), but the determination was carried out some years after breast-feeding had stopped. After controlling for consumption of fish and age, the relation to duration of breast-feeding was no longer significant.

Breast milk and the environment (including other food and hand–mouth activity) were considered for the purpose of the analysis as the two major routes of uptake of DDT by the infants (as compared to malaria control as a source). Bouwman et al. have reported the levels of DDT and its metabolites in fish from the Pongolo Flood Plain, which is about 30 km from Mseleni, and where the same conditions prevail; the maximum intake from eating tigerfish (the most contaminated fish), assuming a mean body weight of 60 kg and a daily fish consumption of 200 g, was 0.98 $\mu g.kg^{-1}.day^{-1}$ (*15*). For the data reported by Kreiss et al. (*14*), assuming the same level of consumption and body weight, we calculated the maximum intake to be 75.3 $\mu g.kg^{-1}.day^{-1}$. Intake of DDT from fish is therefore not responsible for the high levels found in the present and other investigations in the study area (*2, 5, 13*).

If the environment were a major source of DDT in the study area, ΣDDT would increase with infant age. The multiplicative model showed that 44.95% of the variation in ΣDDT was accounted for by infant age; however, the difference in the levels of ΣDDT in milk from primiparous mothers relative to that from mothers with more children permitted identification of two extra variables: parity and concentration of ΣDDT in milk. Parity and infant age are not linearly related, and the regression of the levels of ΣDDT in infant blood with either of these variables provided no information about the duration of exposure. Multiple regression with stepwise selection of variables (Fig. 3), which allowed the introduction of

time as a variable, indicated that 60.5% of the variation was accounted for by parity, 8% by infant age, and only 1.5% by ΣDDT in the milk.

Maternal age and percentage milk fat did not contribute significantly to the model and were excluded. The non-significance of maternal age, which varied linearly with ΣDDT in breast milk, should be noted. The percentage milk fat did not contribute probably because no relationship existed between the levels of ΣDDT, DDT or DDE and this parameter (which, in turn, was also not significantly related to any other parameter). Also, maternal age, although related to parity, was a worse indicator of the level of contamination of breast milk for this group (*5*).

Unexpectedly, the level of ΣDDT in breast milk had very little influence, and its contribution to the model containing the other two variables was not significant ($P = 0.1747$). It was nevertheless included because it improved the model (increasing the coefficient of determination from 68.5% to 70%) and reduced the mean square error by 30%. Also, for the model that accounted for DDE (Fig. 4), the concentration variable was significant.

Two considerations could explain the lack of influence of ΣDDT in breast milk — parity (as a major determinant of concentration) and time. The amount of DDT taken up is determined by its concentration in milk and the length of the lactation period (concentration x time = exposure). If there is little variation in the amount of milk consumed and a constant concentration of ΣDDT in the milk, the quantity of DDT compounds taken in with the milk will only be determined by time. The uptake from other sources (environment) will also be governed by time. Infant age is therefore a direct measure of exposure to DDT; and both parity and infant age would then be the best predictors of such exposure. This holds only if the exposure of the mothers was relatively uniform. In this case, the annual malaria control operations with DDT could be considered as constant, with no other environmental source of this substance. The time of application of DDT was about the same for all cases studied (*1*). Furthermore, the level of DDT in breast milk changes after application of the pesticide (*2*). In cases of different exposure of the mother, the concentration of DDT in breast milk would conceivably have more influence on a predictive model.

In the model infant age alone accounted for 42.3% of the variation of ΣDDT, while parity alone accounted for 60.5%. Parity together with infant age accounted for 68.5% of the variation. It seems that these two variables explain at least part (and not necessarily mutually exclusive parts) of the same variation; this would imply a relationship between them. Infant age, however, reveals nothing about parity, and introducing mathematical interaction between these two variables did not improve the model. Although there might be confounding influences (e.g., the rate of weight gain of the infant, the length of lactation period per infant, and the nonlactating interval between infants), the relationship between parity and ΣDDT in the infant (i.e., the relative contributions of parity and infant age in the model) implies that breast milk rather than the environment was the major source of ΣDDT in the study infants.

Further support for this conclusion is provided by the fact that infant blood had 5% more DDT than the breast milk. Although metabolism and subsequent excretion of DDE by the infant or preferential uptake of DDT from the intestinal to the blood compartment are possible, there is a more logical explanation. Malaria control involves the spraying of DDT (which contains ≤4% of DDE); uptake of DDT from this source (possibly from indoor air or by contact) by the infant could account for the difference. The magnitude of the difference in the % DDT in milk or infant blood could therefore indicate the relative importance of uptake from milk and the environment. This serves as evidence for a secondary route of uptake, other than from breast milk.

Even more support for the above argument is provided by the differences in the models for DDE (Fig. 4) and DDT (Fig. 5). The model for DDE accounted for 76.3% of its variation ($P < 0.001$); parity for 62.7%, and infant age for 7.6%. The concentration of DDE in milk contributed 6%. All the variables were significant. In contrast, only 38.2% of the variation in DDT was accounted for by its model ($P = 0.0067$). Parity accounted for 26.5%; infant age for 6%, and the DDT concentration in milk for 5.7%. All three variables were not significant.

Also, in the study that determined the levels of DDT in serum of the general population, children aged 3–9 years had significantly higher ($P < 0.05$) levels of ΣDDT (168.6 $\mu g.l^{-1}$) than adults aged 20–29 years (60.5 $\mu g.l^{-1}$) (*13*). The initially high levels of serum ΣDDT were ascribed to exposure to contaminated breast milk, and the subsequent reduction to dilution by growth and/or elimination from the body. A regression analysis suggested pharmacodynamic differences between DDE and DDT for the younger (3–29 months), and older (30 to ≥60 months) groups, which are consistent with elimination as a probable, but not the only mechanism of reduction. This in turn indicates that the initial uptake which produced the elevated levels of DDT in the infant must have come from breast milk, since uptake from the environment will remain constant after breast-feeding has stopped and could even increase upon consumption of other food such as fish.

If it is assumed that the infant's only significant source of DDE is breast milk, the predictive value of a model that includes variables which influence exposure will be higher. The DDT in the infant can be taken to be derived from two routes: breast milk and the environment. A model that includes infant age as the only variable associated with the environment will therefore have less predictive value. Variable contamination of food and air (both in- and outdoors) with DDT, as well as the duration of exposure, are some of the uncertainties associated with the model.

Few studies have examined the changes in the concentration of organochlorine compounds in infants as a function of breast-feeding. The levels of polychlorinated biphenyls (PCBs) in samples of blood from a group of infants who were breast-fed increased from 1.1 $\mu g.l^{-1}$ at birth to 3.6 $\mu g.l^{-1}$ three months later, while for a group who were not breast-fed the corresponding increase was from 1.1 $\mu g.l^{-1}$ to 1.6 $\mu g.l^{-1}$ (*16*). Engst et al. reported a slight increase in the level of DDT in body fat from 15 $mg.kg^{-1}$ at birth to 16.4 $mg.kg^{-1}$ thirteen days later, and attributed this to a modest weight loss in the infants (*17*). Eckenhausen et al. found an increase in the level of DDE in blood from 3 $\mu g.l^{-1}$ at 2 weeks of age to 3.9 $\mu g.l^{-1}$ at 3 months postpartum. A slight increase in the levels of PCBs in infant blood due to breast-feeding was also found (*18*). The group of infants who were bottle-fed in the same study exhibited hardly any change in this respect (*18*). A reverse trend, i.e., reduction in the level of ΣDDT in fat samples by almost 50%, has also been reported by Niessen et al. for infants up to 6 months after birth (*19*).

There have been two reports of the change in the levels of DDT in animals. Ando found that the concentrations of DDT in whole suckling rats that had been exposed to DDT via milk increased rapidly from birth and followed a sigmoid curve (*20*). Tomatis et al. followed a different experimental design and analysed mouse fetuses born to dams that had been exposed to different concentrations of DDT (*21*). The ΣDDT concentration in the fetuses was directly related to maternal exposure (dosage) (*21*).

Only one study was found that predicted age-related DDT levels in infants from the levels in milk. In this study Mes et al. plotted lactation time against theoretically estimated accumulated levels of DDT and DDE, derived from the values in milk and in infant body fat (*22*). A sequential analysis of breast milk from 16 women over a 3-month period was used. At 1, 2, 4, and 14 weeks postpartum the respective DDE levels in infant body were estimated graphically to be 0.15, 0.40, 1.0 and 1.85 $mg.kg^{-1}$; for DDT, the respective values were 0.02, 0.07, 0.12, and 0.25 $mg.kg^{-1}$. The model assumed a linear increase in the percentage body fat, with no provision for adsorption by other organs and no correction for excretion (*22*). In this instance, the levels in milk were not correlated with parity. Mes et al. predicted that the infant body burden would reach adult levels within 3 months of breast-feeding. In contrast, the results of the present study show that the infant body burden continued to increase at higher levels of DDT in breast milk.

Wickizer et al. estimated the body burden over a 12-week period for infants exposed to 1.5 $mg.kg^{-1}$ of PCB in milk fat (*23*). The burdens at 1, 2, 4, 6, 8, 10, and 12 weeks, respectively, were 0.25, 0.45, 0.62, 0.75, 0.90, 1.2, and 1.4 $mg.kg^{-1}$ total body weight.

Whether the levels of DDT found in infants constitute a health hazard has not yet been determined. Rogan et al., in a study that examined the effects of DDE in breast milk on infants (*8*), found that the proportion of infants (about 2 weeks postpartum) who exhibited more than four (out of 20) delayed or not-elicited responses increased with the concentrations of DDE in milk. This trend became apparent at 4 $mg.kg^{-1}$ milk fat. The mean level of ΣDDT (containing DDE and the more toxic DDT) was higher. It is therefore possible that infants thus exposed are at risk. The level of DDT in blood (after conversion to serum) was higher than for the general population. Many workers have expressed concern about the possible higher susceptibility of various body systems, e.g., the nervous, immunological and renal systems of infants, which reach maturity after birth (*8, 17, 24–27*).

Our study shows that the levels of DDT and DDE in infants increase with age. This increase could be modelled using parity, infant age, and concentration of the contaminant in the breast milk. For the case of malaria control as a single source of DDT, more than one route of uptake seemed to play a role. However, the major contribution was considered to be uptake from breast-feeding.

Acknowledgements

This work was supported by the Medical Research Council and is published with their permission. We thank Professor C.H.J. Schutte and Dr P.W. le R. Murray for their assistance and encouragement; Dr V. Friendlund, Dr G.M. Short and Mr S. Ngxongo, KwaZulu Department of Health and Welfare, and Mr M.J. Botha, South African Department of Health and Population Development, for their invaluable assistance; Mrs J. Nkomokazi and Mr G. Ngcobo for their excellent technical assistance; and Mrs B. Pflügler, Mr R. Byng and Mrs B. Bouwman for help in preparing the manuscript.

Résumé

Transfert aux nourrissons, via le lait maternel, du DDT utilisé en lutte antipaludique

Dans une partie du KwaZulu, en Afrique du Sud, où on utilise le DDT pour stopper la transmission du paludisme, on a étudié le transfert aux nourrissons du *p,p´*-DDT (1,1,1-trichloro-2,2-bis(4-chlorophényl)éthane) et de ses métabolites par le biais de l'allaitement au sein. Dans cette région, le DDT est appliqué une fois par an sur les murs intérieurs de toutes les habitations au taux de 2 g/m^2.

Des échantillons de sang complet ont été recueillis au moyen d'un tube capillaire (44,7 µl) chez 23 nourrissons par piqûre à l'orteil. Des échantillons correspondants de lait maternel ont été recueillis chez les mères. Le lait et le sang ont été soumis à une chromatographie en phase gazeuse, technique qui n'est toutefois pas assez sensible pour déceler le DDD (1,1-dichloro-2,2-bis(4-chlorophényl)éthane), un métabolite du DDT, dans le sang des nourrissons.

Le ΣDDT moyen (DDT total) dans les échantillons de sang complet était de 127,03 µg/l, tandis que le ΣDDT moyen dans les échantillons de lait maternel était de 15,06 mg/kg (graisses du lait). Une analyse par régression linéaire a montré que le ΣDDT (P <0,01) dans le sang complet des nourrissons augmentait significativement avec l'âge. Une analyse par régression multiple a montré que 70,0% de la variation du ΣDDT étaient dus à des différences au niveau du degré de parité de la mère, de l'âge de l'enfant et du ΣDDT dans le lait maternel. Ces mêmes variables expliquaient 76,3% de la variation du *p,p´*-DDE (1,1-dichloro-2,2-bis(4-chlorophényl)éthylène), mais seulement 38,2% de la variation du *p,p´*-DDT.

Le sang des nourrissons contenait 5% de DDT de plus que le lait maternel (P <0,05; test-*t* bilatéral de Student). Bien que l'on puisse avancer comme hypothèses le métabolisme et l'excrétion du DDE chez le nourrisson, ou l'absorption préférentielle du DDT du compartiment intestinal dans le compartiment sanguin, il existe une explication plus logique. Les opérations de lutte antipaludique comportent la pulvérisation de DDT, qui contient au maximum 4% de DDE. L'absorption de DDT à partir de cette source par le nourrisson pourrait expliquer la différence de teneur en DDT entre le lait maternel et le sang du nourrisson; l'ampleur de cette différence témoignerait de l'importance relative de l'absorption de DDT à partir du lait maternel et à partir de l'environnement, et semblerait démontrer qu'il existe une deuxième voie d'absorption du DDT, s'ajoutant à l'absorption via le lait maternel. Toutefois, la contribution de cette dernière est considérée comme plus importante.

De nombreux auteurs considèrent comme préoccupante la possibilité d'une sensibilité accrue au DDT du système nerveux, du système immunitaire et du système rénal chez le nourrisson, systèmes qui n'atteignent leur maturité qu'après la naissance. La seule étude dans laquelle ont été examinés les effets neurologiques chez le nourrisson du DDE présent dans le lait maternel indique que la proportion de nourrissons (âgés d'environ 2 semaines) présentant plus de quatre réponses (sur 20) différées ou nulles augmentait avec la concentration de DDE dans le lait. Cette tendance se manifestait à partir de 4mg/kg de DDE dans les graisses du lait. Le ΣDDT moyen (qui comprend le DDE et les métabolites plus toxiques du DDT) trouvé dans notre étude était supérieur à cette valeur. Il existe par conséquent une possibilité réelle de risque pour le nourrisson.

References

1. **Sharp, B.L. et al.** Analysis of 10 years of retrospective malaria data from the KwaZulu areas of Natal. *South African journal of science*, **84**: 102–106 (1988).
2. **Bouwman, H. et al.** Levels of DDT and metabolites in breast milk from KwaZulu mothers after DDT application for malaria control. *Bulletin of the World Health Organization*, **68**: 761–768 (1990).
3. *Pesticide residues in food — 1984: report of the Joint Meeting on Pesticide Residues.* Rome, Food and Agriculture Organization, 1985 (FAO Plant Production and Protection Paper, No. 62).
4. **Slorach, S.A. & Vaz, R.** *Assessment of human exposure to selected organochlorine compounds through biological monitoring.* Uppsala, UNEP/WHO/ Swedish National Food Administration, 1983.
5. **Bouwman, H. et al.** Factors affecting levels of DDT and metabolites in human breast milk from KwaZulu. *Journal of toxicology and environmental health*, **31**: 93–115 (1990).
6. **Morselli, P.L.** Clinical pharmacokinetics in neonates. *Clinical pharmacokinetics*, **1**: 81–98 (1976).
7. *Principles for evaluating health risks from chemicals during infancy and early childhood: the need for a special approach.* Geneva, World Health Organization, 1986 (Environmental Health Criteria No. 59).
8. **Rogan, W.J. et al.** Neonatal effects of transplacental exposure to PCBs and DDE. *Journal of pediatrics*, **109**: 335–341 (1986).
9. **Bouwman, H. et al.** Single-step extraction and clean-up procedure for determining serum levels of

DDT, DDE and DDD. *Chemosphere*, **18**: 2085–2091 (1989).
10. **Bouwman, H. et al.** Extraction and clean-up procedure to determine DDT and metabolites in milk. *Chemosphere*, **19**: 1563–1571 (1989).
11. **Radomski, J.L. et al.** Blood levels of organochlorine pesticides in Argentina: occupationally and nonoccupationally exposed adults, children and newborn infants. *Toxicology and applied pharmacology*, **20**: 186–193 (1971).
12. **Morgan, D.P. et al.** Transport of DDT, DDE and dieldrin in human blood. *Bulletin of environmental contamination and toxicology*, **8**: 321–326 (1972).
13. **Bouwman, H. et al.** Malaria control and levels of DDT in serum of two populations in KwaZulu. *Journal of toxicology and environmental health*, **33**: 141–155 (1991).
14. **Kreiss, K. et al.** Cross-sectional study of a community with exceptional exposure to DDT. *Journal of the American Medical Association*, **254**: 1926–1930 (1981).
15. **Bouwman, H. et al.** Environmental and health implications of DDT-contaminated fish from the Pongolo Flood Plain. *Journal of African zoology*, **104**: 275–286 (1990).
16. **Kodama, H. & Ota, H.** Transfer of polychlorinated biphenyls to infants from their mothers. *Archives of environmental health*, **35**: 95–100 (1981).
17. **Engst, R.** [The occurrence of DDT and DDE in the adipose tissue and organs of very young children]. *Pharmazie*, **24**: 673–676 (1970) (in German).
18. **Eckenhausen, F.W. et al.** Organochlorine pesticide concentrations in perinatal samples from mothers and babies. *Archives of environmental health*, **36**: 81–92 (1981).
19. **Niessen, K.H. et al.** Chlorinated hydrocarbons in adipose tissue of infants and toddlers: inventory and studies on their association with intake of mothers' milk. *European journal of pediatrics*, **142**: 238–243 (1984).
20. **Ando, M.** Transfer of 2, 4, 5, 2′, 4′, 5′ -hexachlorobiphenyl and 2,2-bis(*p*-chlorophenyl)-1,1,1-trichloroethane (*p,p′*-DDT) from maternal to newborn and suckling rats. *Archives of toxicology*, **41**: 179–186 (1978).
21. **Tomatis, L. et al.** Storage levels of DDT metabolites in mouse tissue following long-term exposure to technical DDT. *Tumori*, **57**: 377–396 (1971).
22. **Mes, J. et al.** Polychlorinated biphenyls and organochlorine pesticides in milk and blood of Canadian women during lactation. *Archives of environmental contamination and toxicology*, **13**: 217–223 (1984).
23. **Wickizer, T.M. et al.** Polychlorinated biphenyl contamination of nursing mothers' milk in Michigan. *American journal of public health*, **71**: 132–137 (1981).
24. **Egan, H. et al.** Organochlorine pesticide residues in human fat and human milk. *British medical journal*, **2**: 66–69 (1965).
25. **Quinby, G.E. et al.** DDT in human milk. *Nature*, **207**: 726–728 (1965).
26. **Knoll, W. & Jayaraman, S.** [Contamination of human milk with chlorinated hydrocarbons]. *Nahrung*, **17**: 599–615 (1973) (in German).
27. **Klein, D. et al.** Cinétique d'élimination des composés organochlores au cours de la première semaine d'allaitement maternel. *Food and chemical toxicology*, **24**: 869–873 (1986).