X-irradiation before 18.30 h on gestational day 10, defects in which result in congenital hydrocephalus, may be the proliferating precursor cells of the SCO but not those engaged in the specific morphogenetic differentiation. The present study strongly suggests that the dysmorphogenesis of the SCO is primarily involved in the pathogenesis of congenital hydrocephalus induced by maternal X-irradiation. A number of investigators have discussed the functional significance of the SCO in many vertebrate species, but none of the suggestions have been confirmed by direct evidence[2]. Thus, the precise mechanism by which the dysmorphogenesis of the SCO could induce congenital hydrocephalus awaits further elucidation.

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Mineral composition of pigeon milk

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Summary. Mineral analysis of pigeon milk indicates its major elements to be P > Ca > K > Na > Mg (in that order) and trace elements Fe > Zn > Mn > Cu. Whereas the levels of Ca, K, Mg, Na and Mn remain fairly constant in the first week, those of P, Fe, Zn and Cu fall significantly during this period. Compared to cow's and human milk, pigeon milk has definitely higher levels of trace elements. Similarly, the trace mineral content of pigeon milk exceeds that of pigeon egg albumen or yolk. Except for Fe, Mn and Cu, pigeon milk is richer than adult pigeon feed in its mineral content. The Ca:P ratio of pigeon milk increases from 0.3 to 1.1 in the first five days. It appears that the high trace mineral content of pigeon milk is one of the factors contributing to the phenomenal postnatal growth of squabs.
Key words. Pigeon milk; major elements; trace minerals; nutrition; postnatal growth; squabs.

One of the spectacular avian adaptations is the synthesis and secretion by pigeons and doves (Columbidae) of a nutritive material in their crop, popularly known as pigeon milk[1]. The process has close parallelism to mammalian lactation, in that both pigeon milk and mammalian milk are holocrine products controlled by prolactin, and both constitute the most wholesome food for their respective neonates. Unlike mammalian milk, however, pigeon milk is produced by both male and female parent pigeons. In physical consistency the pigeon milk is semi-solid and cheese-like; it is formed by the clumping of sloughed-off crop squamous epithelial cells. The altricial pigeon young (squabs) fed exclusively on this milk show a phenomenal rate of postnatal growth[2,3]. The chemical composition of this unique avian juvenile diet reveals that it is a rich source of proteins and lipids but not of vitamins and carbohydrates[4]. However, except for a few preliminary analyses of proteins and lipids[5-10], practically nothing is known of the growth-promoting properties of pigeon milk. In this paper we report its mineral composition and compare it with that of cow's milk, human milk, pigeon egg albumen and yolk, and adult pigeon feed.

Materials and methods

Domestic pigeons (*Columba livia*) were maintained on a mixed-grain diet of cereals and pulses (supplemented with minerals and vitamins) and bred in the aviary of the Department. Pigeon milk was collected from the crops of 1–5-day-old squabs as described earlier[11]. It must be mentioned that parent pigeons do not store the milk in their crops at any time, so collection from the adult would not be feasible. Any fragments of grains found mixed with the milk were carefully removed, and samples collected on different days were separately pooled and stored at $-20\,^{\circ}C$ until used. The mineral composition (Ca, Mg, Fe, Cu, Mn and Zn) of pigeon milk, pigeon egg yolk and albumen, and pigeon feed was analysed, after digesting the dry samples with a perchloric acid:nitric acid mixture (1:2 v/v), by atomic absorption spectrophotometer (Varian AAS-975). Na and K content was estimated by flame photometry. Phosphorus was determined by the vanadomolybdophosphoric yellow color method. Published data on the minerals of cow's milk and human milk[12] were taken for comparison.

Results

Results on minerals of pooled samples of pigeon milk presented in table 1 indicate (with percentage values in parentheses) that phosphorus (34.80), calcium (22.80), potassium (21.99), sodium (11.14) and magnesium (8.09) constitute the major elements, and that iron (0.85), zinc (0.23), manganese (0.05) and copper (0.03) comprise the trace elements. Changes in mineral composition of pigeon milk during the first five days of secretion are shown in table 2. It can be seen that the levels of Ca, K, Mg and to some extent those of Na and Mn remain, despite small fluctuations, fairly constant. In contrast, the values for phosphorus, iron, zinc and copper fall considerably during this period. Table 3 compares the mineral composition of pigeon milk with that of cow's milk and human milk. Total mineral content of pigeon milk (2.6%), though slightly less than that of cow's milk (3.3%), is about two and half times that of human milk (1.0%). With respect to major minerals the pigeon milk is generally comparable to cow's milk but is certainly richer than human milk. A noteworthy feature, however, is the levels of the trace minerals iron, zinc, manganese and copper, which far exceed the corresponding values met with in both cow's and human milk.

Minerals of pigeon milk were further compared with those of pigeon egg albumen and yolk, and adult pigeon feed (table 4). It is evident that, apart from the higher concentration of K and Na in pigeon egg albumen, pigeon milk and the two egg components are comparable in terms of their major mineral composition. But in respect of trace elements the pigeon milk is richer than either component of the egg. Secondly, in comparison to adult pigeon feed, levels of Na, Ca, P, Zn and Mg in pigeon milk are respectively about 29, 6, 4, 3 and 2-fold higher than those of the former; however, the values for Fe, Mn and Cu are higher in adult pigeon feed.

Discussion

It has been observed that the rate of growth of pigeon squabs in the first three postnatal weeks is such that they reach about twenty two times their birth weight[3]. Available data on the growth rate of young ones of a number of animal species suggest that this is unparalleled. When fed in small quantities to domestic chicks and weaned rats, the pigeon milk also stimulates growth in them[3,4,11]. Although the phenomenal growth of squabs has been attributed to their pigeon milk diet, it is not properly understood which components are involved. Feeding experiments in our laboratory with a synthetic diet whose composition was comparable to that of pigeon milk, did not result in any satisfactory growth

Table 1. The mineral composition of pooled pigeon milk samples

P (mg)	Ca (mg)	K (mg)	Na (mg)	Mg (mg)	Fe (µg)	Zn (µg)	Mn (µg)	Cu (µg)
8.99*	5.89	5.68	2.88	2.09	220.00	59.06	14.57	7.01
±	±	±	±	±	±	±	±	±
0.48	0.33	0.75	0.37	0.31	50.00	2.24	2.29	1.91

*Mean values ± SE of 15 determinations are expressed per g dry weight.

Table 2. Changes in the mineral composition of pigeon milk in the first week

Day of secretion	P (mg)	Ca (mg)	K (mg)	Na (mg)	Mg (mg)	Fe (µg)	Zn (µg)	Mn (µg)	Cu (µg)
1	5.26*	1.79	1.46	0.95	1.10	570.00	50.90	29.57	33.26
2	4.76	2.69	2.92	1.05	1.10	360.00	34.50	20.16	15.75
3	3.86	1.71	3.02	0.80	1.00	60.00	27.90	18.82	7.00
4	4.25	2.06	3.31	0.85	1.60	60.00	27.90	22.85	5.25
5	1.99	2.16	1.56	0.50	0.90	60.00	18.90	34.95	4.38

*Mean values of triplicate analyses are expressed per g dry weight.

Table 3. Comparison of mineral content of pigeon milk with that of cow's milk and human milk

Sample	P (mg)	Ca (mg)	K (mg)	Na (mg)	Mg (mg)	Fe (µg)	Zn (µg)	Mn (µg)	Cu (µg)	Total (mg)
Pigeon milk	899*	589	568	288	209	22000	5906	1457	701	2583.1
Cow's milk	731$	923	1154	385	92	390	2.7	23	154	3285.6
Human milk	115$	278	476	115	22	600	2.3	9.5	310	1006.9

*Values of pooled sample (from table 1) are expressed per 100 g dry weight. $Data for comparison are taken from non-colostral pooled samples[12].

Table 4. Comparison of mineral composition of pigeon milk with that of pigeon egg albumen, yolk and adult pigeon feed

Samples	P (mg)	Ca (mg)	K (mg)	Na (mg)	Mg (mg)	Fe (µg)	Zn (µg)	Mn (µg)	Cu (µg)
Pigeon milk	8.99*	5.89	5.68	2.88	2.09	220.00	59.06	14.57	7.01
Pigeon egg albumen	7.99$	3.42	11.86	11.79	2.51	48.78	10.27	0.00	0.00
Pigeon egg yolk	9.23	1.36	2.30	0.80	0.69	210.00	57.66	5.80	0.00
Adult pigeon feed	2.56	1.08	4.77	0.10	1.43	340.00	24.40	48.38	14.00

*Data for comparison are taken from table 1. $Other values are mean of triplicate analyses and are expressed per g dry weight.

of squabs[13]. Detailed analyses of proteins and lipids indicated that the pigeon milk has essential amino acids and fatty acids in proportions that match those present in human milk[3]. Moreover, it has also been found to be a source of dietary proteins whose digestibility is better than that of casein and comparable to that of muscle proteins and egg-albumen[3].

It is well known that macro and micro elements have both nutritional and metabolic significance. An interesting feature of pigeon milk is its trace mineral content which in comparison to mammalian milk, and pigeon egg albumen and yolk, appears to be very high. Some of these minerals could be derived from the parent pigeon diet, as the latter has a high proportion of these elements (table 4). In birds, Zn is known to facilitate proper development of feathers, legs and skin. It also affects avian reproduction, bone formation and the metabolism of nucleic acids, proteins and carbohydrates[14]. Fe and Cu in turkey poults promote growth and help maintain normal levels of haemoglobin and packed cell volume[15]. These elements also faciliate normal development of blood, liver, muscle, skeleton and bone-marrow in birds[16]. Mn in association with iron and copper participates in avian growth and reproduction[16]. Decades ago it was observed that pigeon milk resembles rabbit milk in chemical composition[7,17]. However, we find that whereas the Ca content of pigeon milk compares well with that of rabbit and hare milk, its phosphorus level is almost twice that of the latter. Similarly, K, Na, Zn, Fe and Cu levels are very high in pigeon milk compared to those met with in rabbit or hare milk[18]. The ratio of K:Na in pigeon milk is about 2:1 whereas in most mammalian milk it is roughly 3:1, resembling the intracellular fluid composition[19]. It was observed earlier that the type of food furnished by the pigeon crop secretion is similar to that provided by the egg before hatching[20]. Our results given in table 4 lend support to this early finding, at least in respect of some, it not all, minerals. Pigeon milk is notably richer in Fe content, like the milk of many mammalian species bearing undeveloped young (monotremes, marsupials[21,22]). It can be inferred from table 2 that there is an increase in the Ca:P ratio of pigeon milk from 0.3 on day 1 to 1.1 on day 5 of secretion. The situation is the reverse in seal's milk collected 5 days postpartum[23], and also in domestic horse milk[24].

Current experiments in our laboratory suggest that pigeon milk has a growth factor that causes proliferation and keratinisation of epidermal tissues in new-born mice[3] and induces mitogenesis in cultured hamster fibroblasts[13]. Therefore it is likely that several factors including the minerals of pigeon milk contribute to the rapid development of altricial squabs, in which the gain in body weight is coupled with preparation for flight at 3 weeks of age.

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