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Passage of Particles through the Wall of of the Gastrointestinal Tract

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In the normal process of digestion, not only substances in solution are absorbed. Solid, undissolved particles in macrocorpuscular form, are "kneaded" into the mucosa during their passage through the digestive tract. These particles in the micrometer size range pass between the epithelial cells into the subepithelial layer. From here they are transmitted both by the lymph vessels and by the mesenteric veins into the circulation, where they remain for a considerable time. This phenomenon, termed persorption, was investigated in detail.

Absorption

In the physiology of digestion, the concept of absorption is taken to mean the uptake of a substance by the absorptive cells (enterocytes) of the intestine. This takes place by three mechanisms: diffusion is a passive process for the enterocyte, in which substances of lower molecular dimensions (<250 mol) pass through it; in active transport, substances of higher molecular dimensions (>250 mol) are carried through the enterocytes with the help of enzymes; cytopempsis (micropinocytosis) transports particles in the nanometer (nm) size range through the enterocytes. The transportation through the enterocytes is effected in small vesicles (plasma membrane vesiculation). Also small crystals and fibers of nanometer size can be incorporated by means of cytopempsis (Fig. 1).

Persorption

In addition to the process of absorption, however, macrocorpuscular particles, whose diameter is well within the micrometer (μm) range, are regularly incorporated. This process has been observed in detail *(1)* under the heading persorption (Figs. 2 and 3).

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Mechanisms of Persorption

Rats, rabbits, chickens, guinea pigs, dogs, and pigs were fed particles in suspension, or the latter were given by esophageal or rectal tube. Starch granules, cellulose particles, powdered rabbit hairs, charcoal, pollen, spores, polyvinyl globules, and silicate crystals were used. After various time intervals, sections of intestine were removed and examined histologically. Isolated particles were found lying between the cells of the epithelial layer. This was observed especially in the area of desquamation on the top of the villi, but also between the villi near their foot,

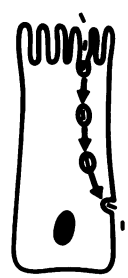


FIGURE 1. Cytopempsis, a well known type of absorption. Particles in the nanometer size range can be channeled through the absorptive cell (enterocyte) by a pinocytosis-like process in minute bubbles with a diameter of up to 50 nm.

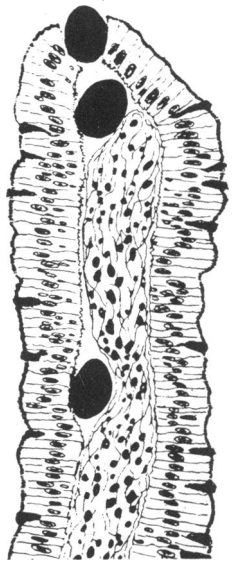


FIGURE 2. Persorption of large corpuscular particles in the micrometer size range. The particles pass between the cells into the subepithelial region. They are carried away in the portal circulation and the chyle.

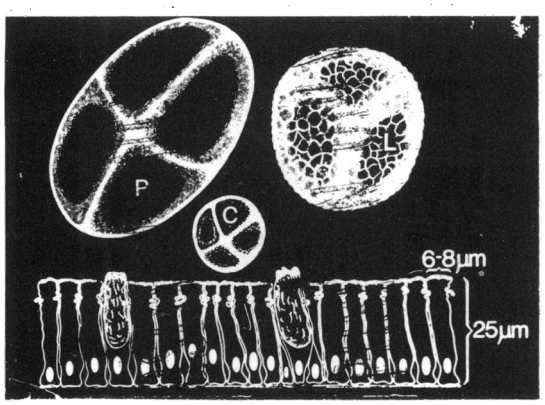


FIGURE 3. Epithelial layer of small intestine: enterocytes and two goblet cells. Comparison to the size of persorbable particles: *(P)* potato starch granule; *(L)* lycopodium spore; *(C)* corn starch granule.

where the intervillous space is small. Isolated particles were found also in the subepithelial region of the mucosa, in the so-called Gruenhagen's space. In the deeper layers of the wall, the particles were already within the lumen of lymph and blood vessels (Fig. 4).

Persorption is possible wherever the intestinal mucosa is covered by a single layer epithelium. Mechanical factors must be considered: the motor function of the muscularis mucosae and also the transmitted pulsation of blood vessels.

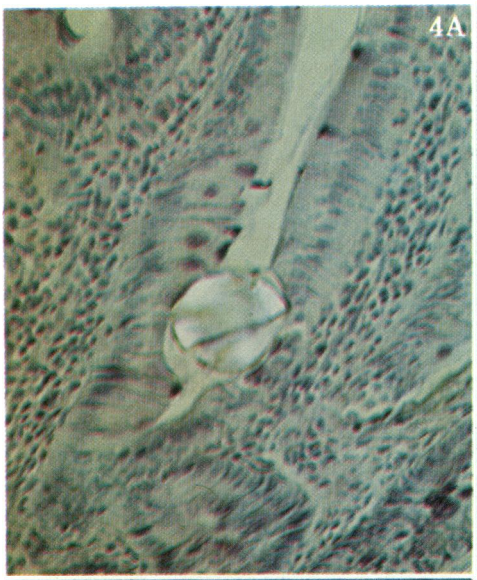
Primary transportation of persorbed particles from the digestive tract may take place in the chyle and by the portal circulation.

In the Chyle: After feeding or rectal administration of particle suspension to rats, rabbits, chickens, dogs, and guinea pigs, particles were found in histological sections within the lumen of lymph vessels, but only in parts of the mesentery corresponding to segments of the intestine in which the particles were found. Where the intestinal segments contained no particles, the lymph vessels were also devoid of particles. This observation confirms the primary transportation of persorbed particles in the chyle.

By the Portal Circulation: Blood was taken from the portal circulation and at the same time from the aorta of dogs fed starch. Blood from the mesenteric vein in segments of the intestine which were filled with starch contained markedly more starch granules than the arterial blood, whereas in segments devoid of starch, it contained somewhat less starch granules than the corresponding arterial blood (Fig. 5). This observation confirms the primary portal transportation of persorbed particles.

Persorbed particles are thus transported by both the lymphatic system and the portal system from the intestinal wall. We fed dogs different types of particles. Two hours later some of these particles were regularly found in body fluids, in the chyle taken from the thoracic duct, in the blood, in the bile, and in the urinary bladder. All these investigations are technically quite simple. The most suitable diameter of particles for the experimental study of persorption is between 15 and 75 μm, particles such as stained cellulose fibers, spores, pollen, plastic globules, crushed crab and lobster shells, were studied. We used also powdered rabbit hairs and found them in the blood, in the thoracic duct and also in the bile. We used ascaris eggs, silicate crystals in different sizes, powdered asbestos fibers, and diatomaceous earth. The largest particles we have ever seen in the lymph were

FIGURE 4. Starch grains at various stages of persorption through intestinal wall. ➔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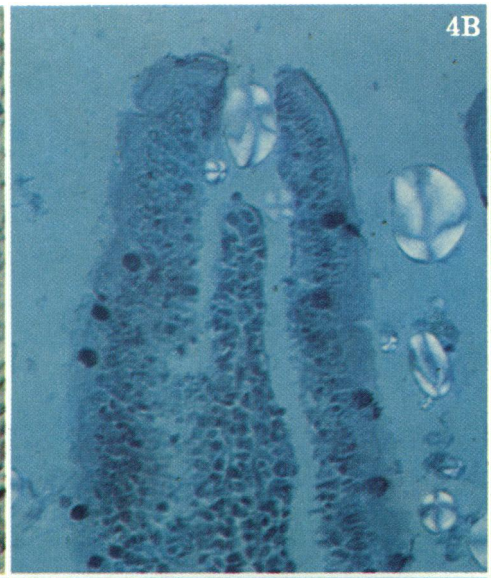
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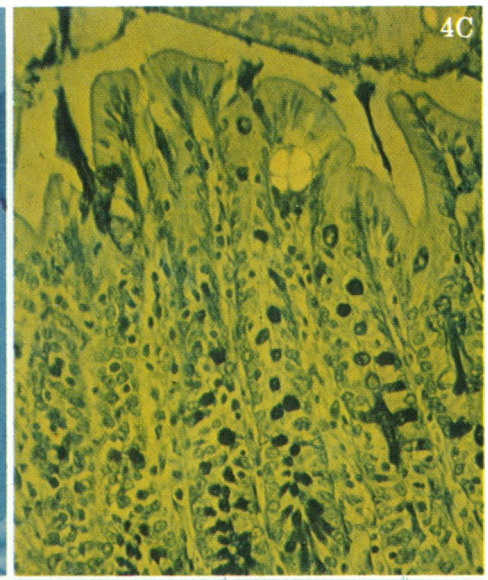
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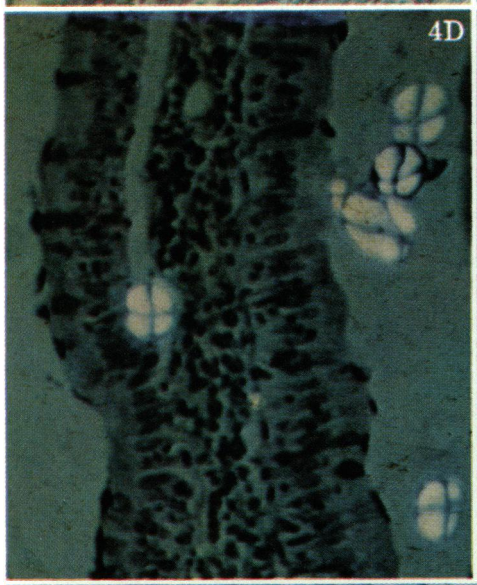
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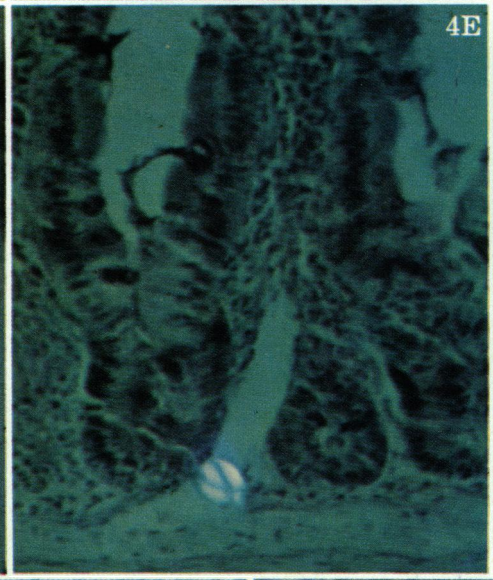
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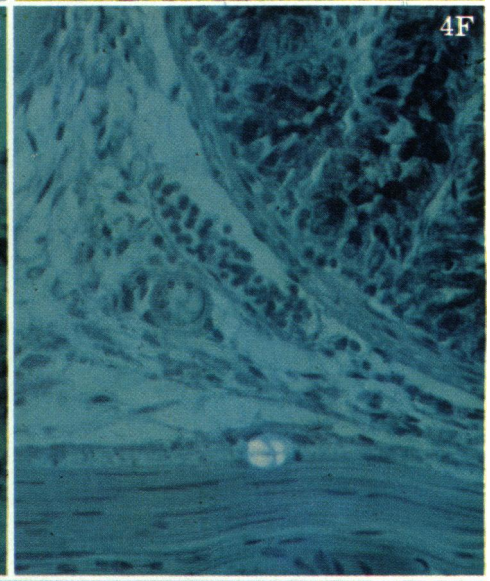
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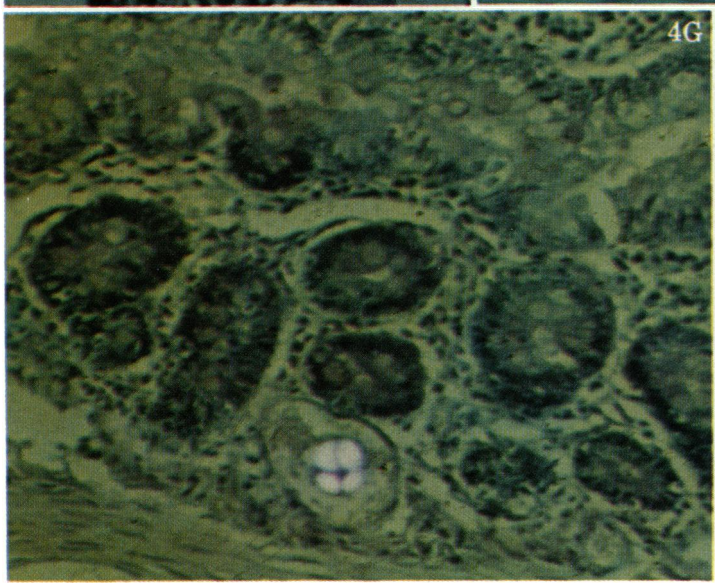
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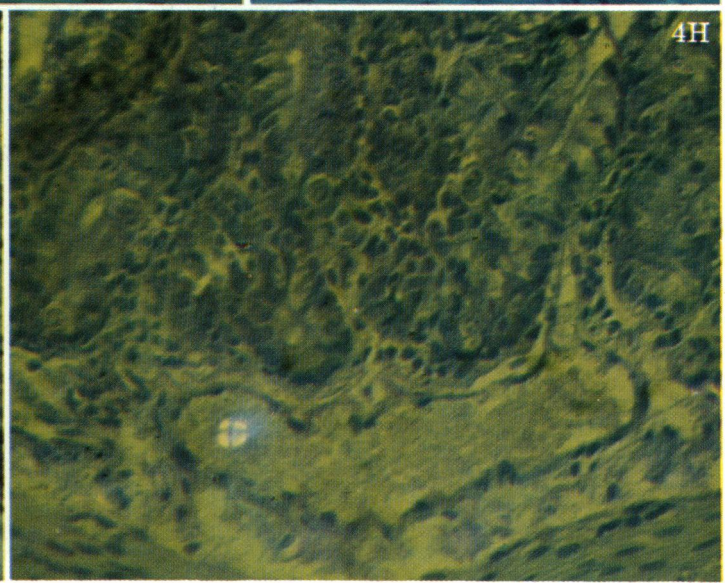
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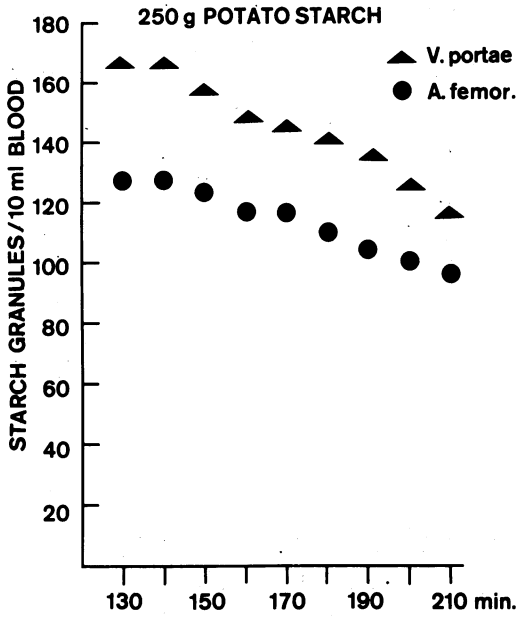


FIGURE 5. Experimental demonstration of primary portal transportation of persorbed particles from the intestinal wall in dogs (n=9) after they had been fed 250 g of potato starch. Simultaneous 10-ml samples of arterial and of portal vein blood were drawn (splenic vessels ligated). Number of potato starch granules per 10 ml of blood. Significantly more granules were found in the portal than in the arterial blood.

rounded silicate crystals with a diameter of 150 μm. Such enormous particles are very rarely found, however. Particles with a diameter up to 90 μm are found quite often. In the chyle of dogs fed metallic iron powder we found iron particles up to 52 μm; they could be identified on account of their ferromagnetic properties; the identity was confirmed also by x-ray analysis. In the lymphatic fluid of a patient with chylothorax we found cellulose particles and starch granules after intake of uncooked cereals. Potato starch granules are particularly suitable as models for such experiments in man. The diameter of potato starch granules varies between 5 and 110 μm (Fig. 6).

Quantitative Observations

The rate of persorption was investigated on subjects in a wide range of variations. Model particles for such investigations were starch granules (corn, wheat, potato, and others). The granules were rendered visible by the polarization method and/or by staining with Lugol's solution. The actual numbers of starch granules were determined at different times after consumption of a standard amount of starch products. In these investigations our team collected more than 10,000 individual values, each from a 10 ml sample of venous blood. Each sample was hemolyzed and centrifuged. In numerous investigations carried out on themselves by our team the number of starch granules in the blood at a given time could be shown to depend on a large number of factors. An important role is played by the quantity of particles supplied and by the muscular activity of the intestine.

When juvenile subjects were given 200 g potato starch, the number of persorbed starch granules in the blood reached a first peak after 10 min, a second peak after about 90–120 min. Similar numbers of granules were found in the blood after consumption of corn starch. The number of starch granules in the blood did not differ markedly when 200 g corn starch with 48.000 million granules was consumed from that when 200 g potato starch with "only" 2400 million granules was ingested. There were significant differences in this series of experiments, however, depending on whether 100, 200, or 300 g of the starch was consumed (Figs. 7*a*.).

In the course of these quantitative studies of the actual number of starch granules in the circulating blood, many other observations were made, some of which may be listed here (Figs. 7*a* and 7*b*). During deep physiological sleep, an increased rate of persorption was observed, while in barbiturate sleep the number of persorbed granules decreased.

Under the influence of cigarette smoking, the rate of persorption is clearly increased. (Fig. 7*b*).

When coffee was ingested at the same time, the number of persorbed granules was significantly higher; this was not observed after administration of so called caffein-free coffee. Higher rates of persorption were also observed on injecting caffeine, whereas atropin reduced the rate. After injection of prostigmine, considerably more starch granules were found in the blood. (Fig. 7*b*).

Young subjects showed a different rate of persorption from older ones (Fig. 7*b*).

Elimination of Persorbed Particles

Elimination of persorbed particles was observed in the urine. In the laboratory animal, elimination of these particles was observed after temporary embolization of glomerular vessels in Bowman's capsule (Fig. 8).

Extravasation from the vessels in the pulmonary alveoli also takes place after temporary embolization of the minute vessels.

The passage of orally administered particles into the cerebrospinal fluid was observed in both animals and in human subjects.

Passage into the peritoneal cavity of orally administered particles was observed in animals and in human subjects with ascites.

Elimination of granules into the milk was observed in lactating women after oral administration of starch. It is worth mentioning that this elimination can be seen within a few minutes after ingestion of the starch; a maximum was reached within 12–15 min.

Transplacental passage of particles was confirmed. Such particles were demonstrated in the cord blood of newborn infants when the mother was given starch about 1 hr previously. This observation we made also in animals.

Elimination of particles into the bile was also confirmed. Granules can be demonstrated in the bile 12 min after administration of starch. The same observations were made also with other particles: stained cellulose fibers, silicate fibers, and powdered lobster shells.

Phagocytosis of Persorbed Particles

Phagocytosis by micro- and macrophages was observed in the peritoneal cavity and in the spleen. Material for these studies were starch granules and silicate fibers.

Enzymatic Degradation

Enzymatic degradation of starch granules in the body fluids was demonstrated. This degradation of persorbed starch granules is most easily seen in the peritoneal cavity.

Deposition

Deposition of embolized starch granules and of other persorbed particles in the lumen of the smallest vessels was observed in aminals after long-term oral administration. In pigs, dogs, chickens, and rats fed with particles, we found individual particles as microemboli in the lumen of the smallest vessels a long time later.

REFERENCE

1. Volkheimer, G. Persorption, Thieme-Verlag, Stuttgart, 1972.

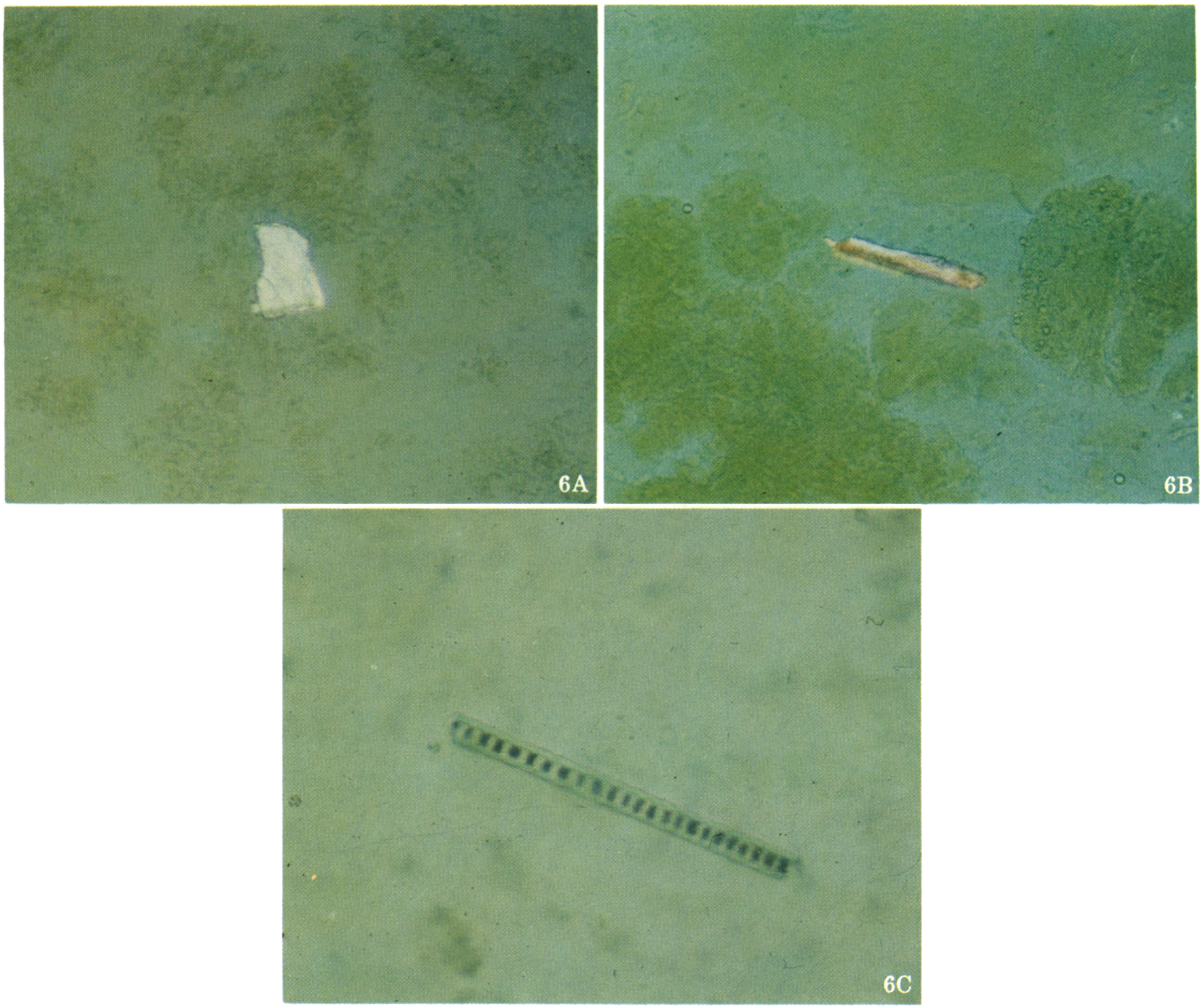


fig. 6: Two hours after feeding of particles to dogs these particles were regularly found in the chyle taken from the thoracic duct.

(a) edged silicate crystals 40 x 50 µm
(b) cellulose fibers (stained) 15 x 85 µm
(c) powdered rabbit hair 16 x 212 µm

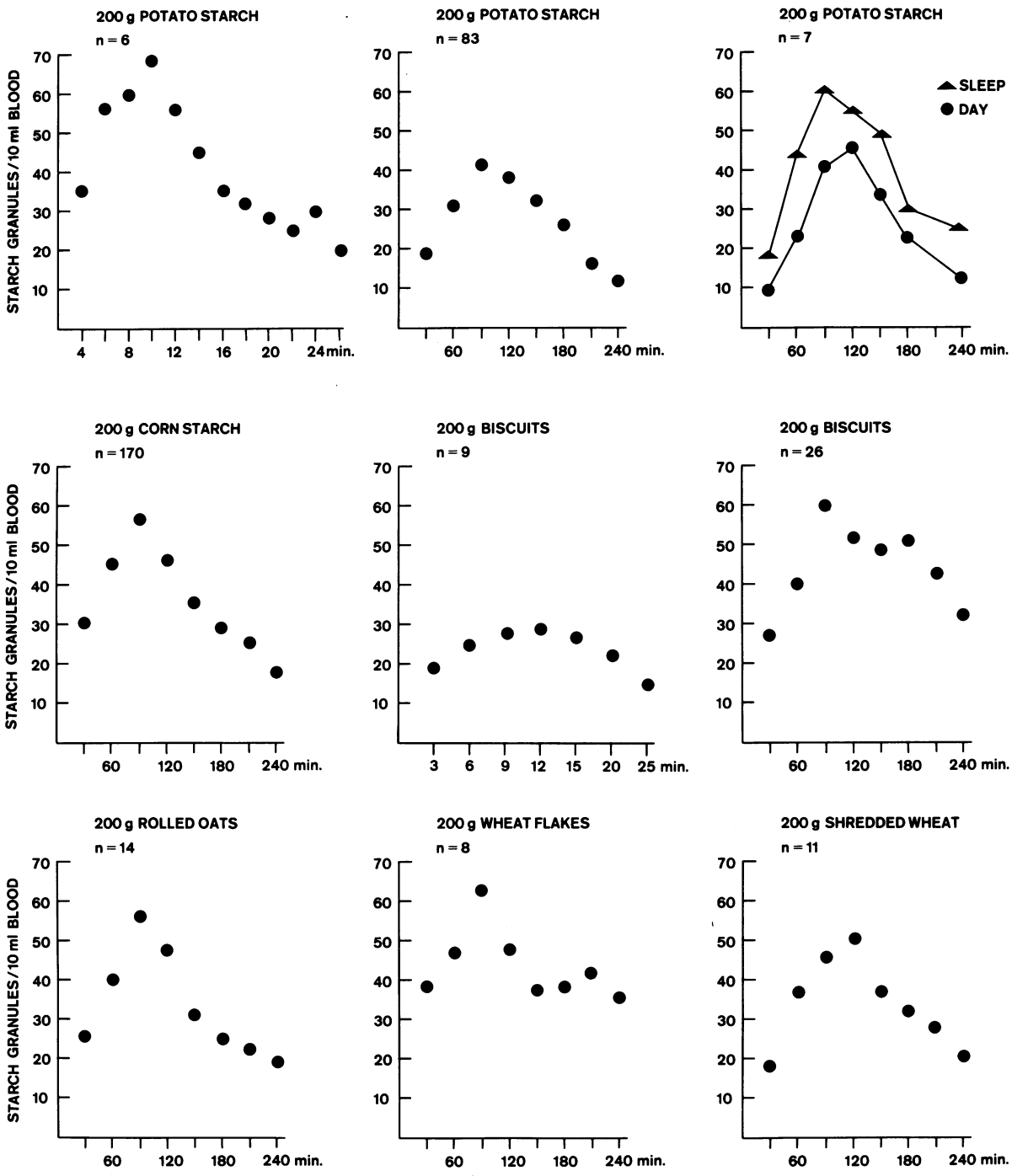


FIGURE 7*a*. Number of starch granules per 10 ml blood after oral administration of starch or of starch-containing food to trial subjects.

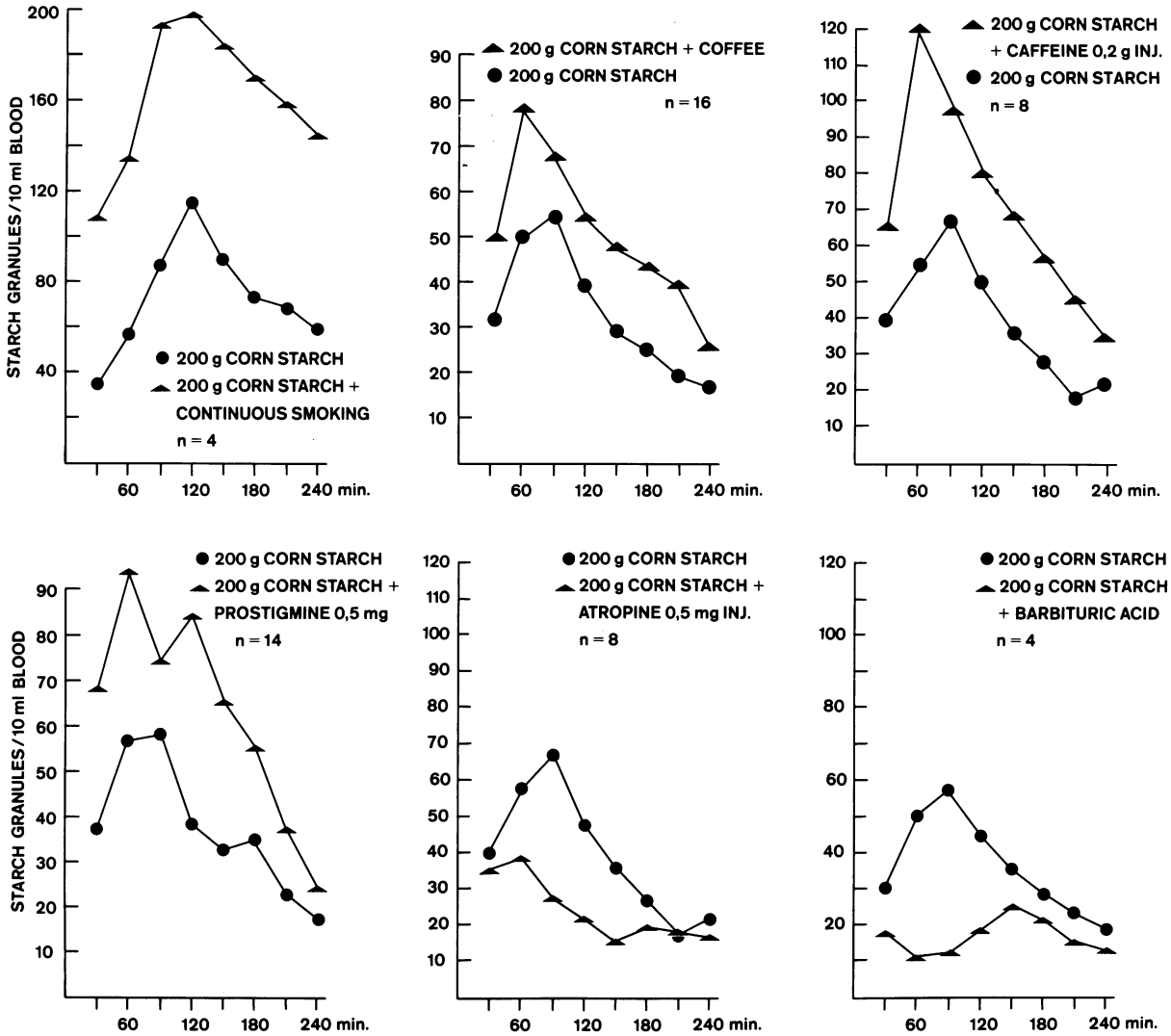
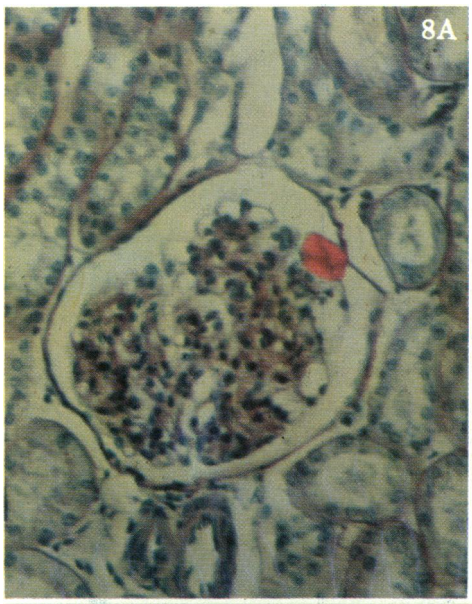


FIGURE 7*b*. Number of starch granules per 10 ml blood after oral administration of starch or starch-containing food to trial subjects, showing influence of smoking, coffee, drugs, and age.

FIGURE 8. Fate of particles after persorption: *(A)* in glomerular tuft; *(B)* pollen grain in pulmonary tissue, growing out; *(C)* in brain tissue; *(D)* enzymatic degradation on persorbed potato starch granule in the peritoneal cavity; *(E)* phagocytotic degradation in spleen. →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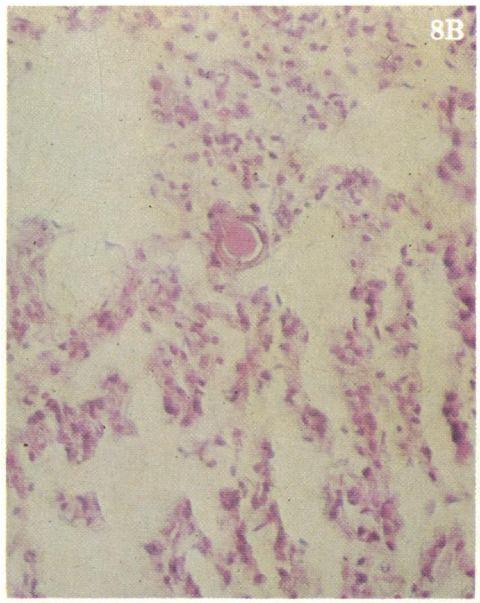
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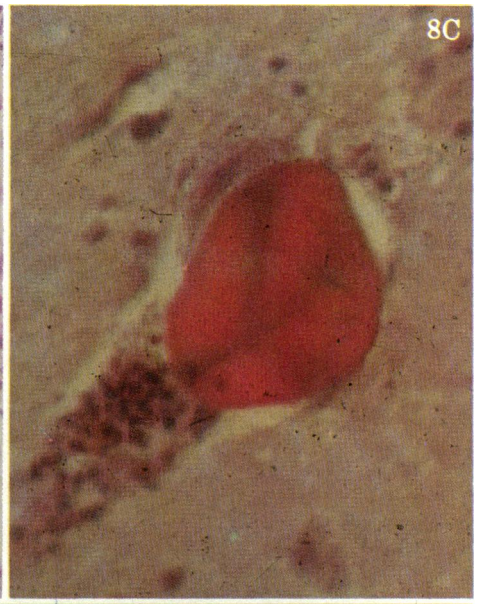
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