

Department of Anatomy (Prof. T. YAMAMOTO), Faculty of Medicine, Kyushu University,
Fukuoka, Japan

An Electron Microscope Study of the Intestinal Absorption of Medium Chain and Long Chain Triglycerides in the Rat

Yasufumi OHSHIMA

Received December 6, 1976

Summary. The ultrastructural changes in the intestinal absorptive cells of the rat during the absorption of triglycerides, particularly medium chain triglyceride (MCT), were studied by electron microscopy. In the absorptive cell of rats fed with MCT, the agranular endoplasmic reticulum in tubular form was remarkably proliferated throughout the cytoplasm as compared with that of fasting rats. The granular endoplasmic reticulum was mostly transformed into the same tubulo-vesicular form as the agranular endoplasmic reticulum. Chylomicra, which were consistently observed in the endoplasmic reticulum of the intestinal absorptive cell of rats fed with long chain triglyceride (LCT), did not appear in that of MCT-fed rats, although small lipid particles were noticed within it. The Golgi lamellae decreased in number and length. During the absorption of MCT, the central lacteal contained some lipid particles which were smaller in size than the chylomicro which appeared in the LCT-fed rats. These evidences might suggest that the majority of MCT administered was transported through the absorptive cell without reesterification in the endoplasmic reticulum into the portal vein system, and only a minor part of the MCT given was transported via the central lacteal after reesterification.

It has been shown that the absorption and metabolism of triglycerides in the intestine differ depending on the carbon chain length of the fatty acids constituting triglycerides in question. Long chain triglycerides (LCT) (carbon chain length of above C: 16), following oral administration to animals, are hydrolyzed by a pancreatic lipase into fatty acids and monoglycerides within the intestinal lumen, and then fatty acids and monoglycerides pass through the plasma membrane of microvilli of the absorptive cell by diffusion (STRAUSS, 1966; CARDELL et al., 1967). After resynthesis to triglycerides within the agranular endoplasmic reticulum (SENIOR and ISSELBACHER, 1960, 1962; SJÖSTRAND and BORGSTRÖM, 1967), they are transported into the lymph as a chylomicro which is a kind of lipoprotein. On the other hand, in the absorption of medium chain triglycerides (MCT) (carbon chain length; C: 6–10), MCT are hydrolyzed easier than LCT by a pancreatic lipase (VALDIVIESO and SCHWABE, 1965a, b; GREENBERGER et al., 1966) and then medium chain fatty acids are transported in unesterified form into the portal vein system rather than into the lymph as triglycerides (BLOOM et al., 1951; KIYASU et al., 1952; BORGSTRÖM, 1955; BLOMSTRAND, 1955; HASHIM et al., 1964; HYUN et al., 1967; KAYDEN and MEDICK, 1969).

An electron microscope study has been performed by some workers in respect to the structures involved in the intestinal absorption of LCT (WEISS, 1955; PALAY and KARLIN, 1959; LACY and TAYLOR, 1962; LADMAN et al., 1963; CARDELL et al., 1967; HIGGINS and BARRNETT, 1970; FRIEDMAN and CARDELL, 1972a, b). These studies, together with the biochemical investigations (SENIOR and ISSELBACHER, 1960 and 1962; DAWSON and ISSELBACHER, 1960; SJÖSTRAND and BORGSTRÖM, 1967), have demonstrated that the endoplasmic reticulum in the absorptive cells is the site of triglyceride

resynthesis and both the Golgi complex and the endoplasmic reticulum are involved in the intracellular transport of LCT. Medium chain fatty acids, however, are known to be hardly resynthesized to triglyceride in the intestinal absorptive cells (DAWSON and ISSELBACHER, 1960; GELB and KESSLER, 1963; GREENBERGER et al., 1965 and 1966; BRINDLEY and HÜBSCHER, 1966). Since there seem to be only a few papers dealing with the morphological aspect of MCT absorption (McKAY et al., 1967), very little is known about the detailed ultrastructural aspect of MCT absorption in the intestine.

The present study was carried out to clarify the morphological basis of the absorption mechanism of MCT in comparison with that of LCT.

Materials and Methods

The absorption studies were carried out by using young female rats (body weight: 125–240 g) of the Wister strain. After fasting for 24 hrs, two groups of rats were given orally by means of syringe a dose of 1.5 ml of MCT (trioctanoin) or 1.5 ml of LCT (soybean oil) respectively. Trioctanoin is a triglyceride of octanoic acids. The main fatty acid components of soybean oil are linoleic acid (18 carbon chain length) and oleic acid (18 carbon chain length) (BROCKERHOFF, 1966).

Thirty minutes following administration of fats all the rats were anesthetized by ethylether and then the upper jejunum was exposed. Immediately after removal, a small piece of the jejunum was cut into small bits. These specimens were transferred into the fixative. In the controls, the rats were fasted for 24 hrs and then the jejunum was removed and cut as described above.

All the materials were fixed in 3% glutaraldehyde buffered with Millonig's 0.1 M phosphate solution at pH 7.4 for two hrs at room temperature. After glutaraldehyde-fixation, the specimens were rinsed in a few changes of the same buffer and post-fixed in 1% osmium tetroxide buffered with the same solution. The materials were dehydrated in a series of graded ethanol and embedded in Epon epoxy resin.

Thin sections for electron microscopy were cut with glass knives on a Porter-Blum MT-1 ultramicrotome, stained with lead tartrate and examined in a Hitachi HU-12A electron microscope with an accelerating voltage of 75 kV. Thick sections for light microscopy were made in the same way, stained with toluidine blue and observed in an ordinary light microscope.

Observations

1. Light microscopy

Fasted rat: Absorptive epithelial cells were lined on the surface of the intestinal villi. They, except for absorptive cells at the tip of the intestinal villi, did not contain any lipid droplets detectable under the light microscope. Lipid droplets were infrequently observed in a few absorptive cells of the tip of the intestinal villi. In the core of the villi, blood vessels were situated beneath the epithelial cells, but a lymphatic vessel (central lacteal) which contained some lipid droplets was occasionally observed in the center of the villus.

Rat fed with MCT: Lipid droplets were not found in any absorptive cell. The lamina propria of the villi also did not contain lipid droplets. Blood vessels were clearly observable. It was considerably easy to perceive the central lacteal. Blood vessels did not contain lipid droplets at all, whereas a few lipid droplets appeared in

the central lacteal though very infrequently.

Rat fed with LCT: A number of lipid droplets were accumulated in the cytoplasm of the absorptive cells. Generally the absorptive cells in the more distal portion of the villus contained more abundant lipids than those proximally situated. Lipid droplets were concentrated mainly in the supranuclear area of the cell and in the intercellular spaces between two adjacent absorptive cells. Many lipid droplets were also seen in the intercellular spaces of the lamina propria of the villus. A distended central lacteal was identified by the bluish-brown color of its lumen. It occupied a considerable portion of the lamina propria of the villus. Blood vessels were clearly observed but lipid droplets could not be detected in their lumen.

2. Electron microscopy

Fasted rat: The intestinal absorptive cell was tall and columnar, and its luminal surface was tightly provided with numerous microvilli. The flattened basal surface rested on a continuous thin basal lamina. The lateral surface showed foldings which were interdigitated with those of adjacent cells. Two adjacent absorptive cells were attached to each other just below the base of the microvilli. This attachment showed a typical junctional complex which consisted of a tight junction, an intermediate junction and desmosomes. Occasionally desmosomes were observed in the lower part of the lateral cell surface. The nucleus was situated in the basal half of the cell. In the cytoplasm the endoplasmic reticulum was observed distributed from the Golgi zone to the area just below the terminal web. Cisterns of the granular endoplasmic reticulum appeared in profile as paired lines studded with ribosomes (Fig. 1). The granular endoplasmic reticulum in cisternal profile was arranged parallel to the long axis of the cell occasionally making an intimate association with mitochondria. The agranular endoplasmic reticulum which was found as a loosely woven network of convoluted tubules was conspicuous in the cytoplasm immediately beneath the terminal web (Fig. 1).

The Golgi complex consisting of the usual lamellae, small vesicles and larger vacuoles was located just above or lateral to the nucleus. There were usually some smaller coated vesicles in the Golgi area. In some cells, the vacuoles and the dilated ends of lamellae of the Golgi complex contained small particles 70–100 nm in diameter with less electron opacity which resembled a lipid droplet in appearance. The granular endoplasmic reticulum that was rarely observed in close proximity to the outermost saccule on the forming face of the Golgi complex was devoid of ribosomes on the membrane surface opposite the Golgi lamellae.

Free ribosomes were distributed throughout the cytoplasm except for the terminal web region. They were most prominent in the supra-Golgi area. The basal cytoplasm of the cell far from the nucleus was scant of cell organelles except for free ribosomes and a small number of coated vesicles.

The central lacteal was situated in the middle of the intestinal villus, however, it was difficult to detect since its lumen was usually collapsed. Along the endothelial junctions the cytoplasmic process overlapped on the adjacent endothelia. In places, the junction showed complicated appearances, in which endothelial processes were multi-layered. Smooth muscle cells occurred around the central lacteal. Fenestrated blood capillaries were situated at the peripheral zone of the villous core, or immediately beneath the epithelial cells. The fenestration was prominent in the endo-

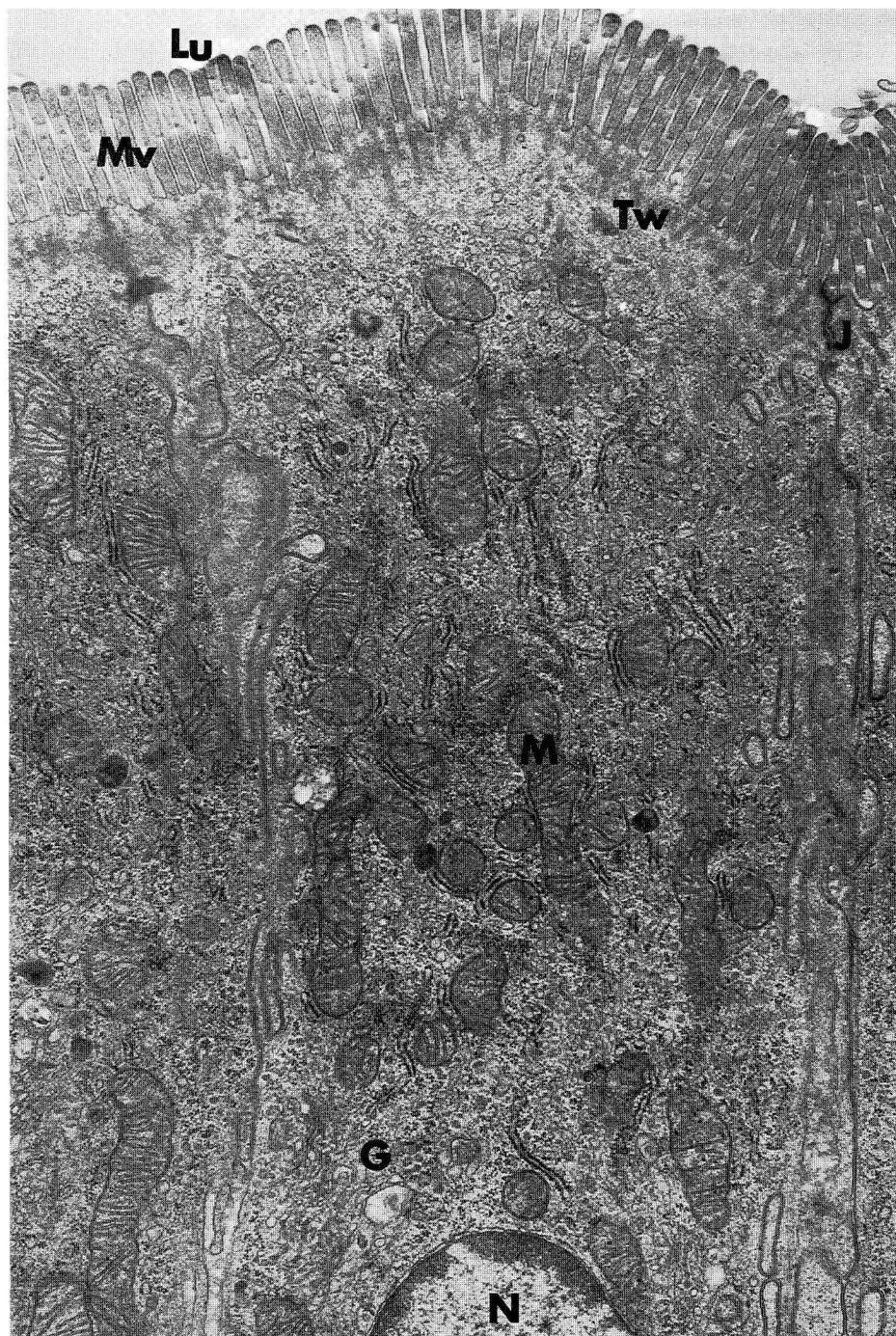


Fig. 1. An intestinal absorptive cell from a fasted rat. No lipid droplets are seen in the endoplasmic reticulum. *Lu* intestinal lumen, *Mv* microvilli, *G* Golgi complex, *J* junctional complex, *N* nucleus. $\times 16,000$

thelial cell facing the epithelial cells. No lipid droplets were found in the lumen of blood capillaries.

Rat fed with MCT: In some absorptive cells at the tip of the intestinal villus, the microvilli showed vesiculations which seemed to represent a sort of destructive alteration, but these were not observed in those of fasted and LCT-fed rats; that is, a part of the microvillus was torn in small vesicles (Fig. 2). This alteration occurred at any level of the microvillus. There were no lipid droplets in the clefts between microvilli.

Apical pits and pinocytotic vesicles in the terminal web did not increase. Lipid droplets were not observed in the terminal web area. Some smooth endoplasmic reticulum invaded into the lower area of the terminal web. The endoplasmic reticulum

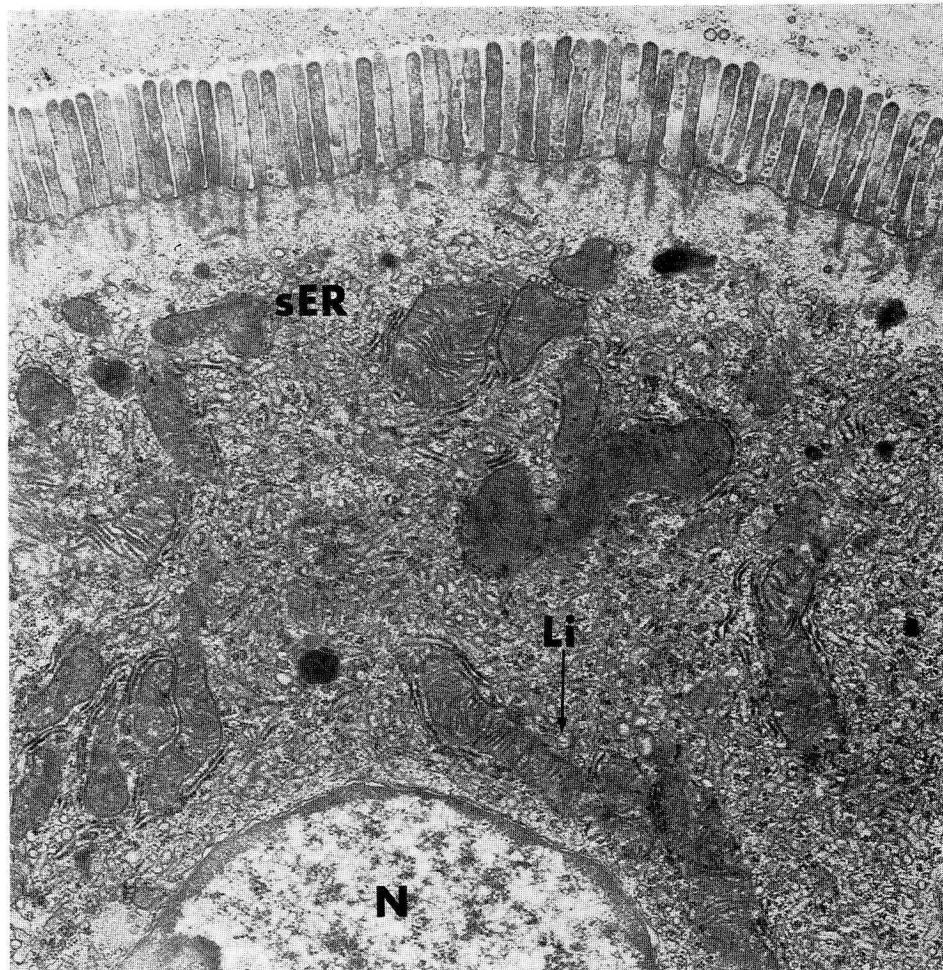


Fig. 2. An absorptive cell from an MCT-fed rat. The agranular endoplasmic reticulum (sER) increases in the cytoplasm. Slightly electron opaque lipid particles (Li) are seen in the endoplasmic reticulum. N nucleus. $\times 18,000$



Fig. 3. Apical cytoplasm of an absorptive cell during MCT absorption, showing the tubular endoplasmic reticulum at higher magnification. Cistern of granular endoplasmic reticulum (*rER*) widens. A lipid particle (*Li*) is seen in the endoplasmic reticulum. $\times 54,000$

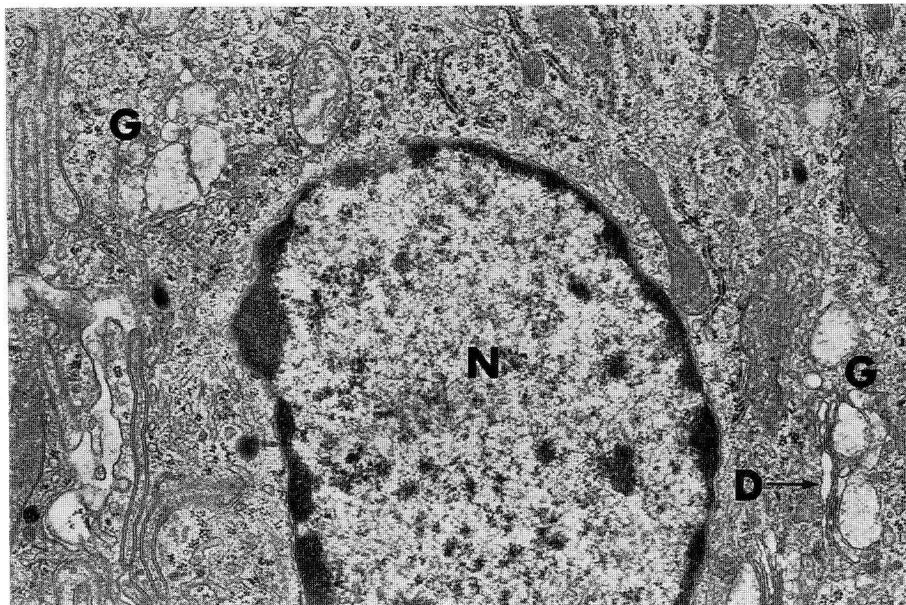


Fig. 4. Perinuclear portion of an absorptive cell during MCT absorption, showing the Golgi complex (G). The Golgi vacuoles contain several small lipid droplets. A wide cistern (*D*) appears on the forming face of the Golgi complex. The intercellular spaces enlarge slightly $\times 18,000$

showed some alterations during MCT absorption; the granular endoplasmic reticulum, which was ordinarily arrayed parallel to the long axis of the absorptive cell, diminished in number and length, and transformed into tubular form. Cisterns of the granular endoplasmic reticulum showed a focal dilation with the same dimension as the agranular endoplasmic reticulum (Fig. 2, 3). In some granular endoplasmic reticulum, both or either end of cisterns dilated and ribosomes tended to be detached from the surface of its membrane. The agranular endoplasmic reticulum proliferated throughout the cytoplasm, especially remarkable at the supranuclear area. The agranular endoplasmic reticulum exhibited branching or anastomosing tubules which were woven into complex networks. There was a slightly electron opaque particle in some vesicles of the agranular endoplasmic reticulum (Fig. 2, 3); however, the agranular endoplasmic reticulum did not develop to a vacuole containing such a lipid droplet as observed in the rat fed with LCT.

The Golgi complex was usually located at the supra- and lateral-nuclear zone of the cytoplasm. The Golgi lamellae were shorter in length, and decreased in number. Frequently, a single wide cistern appeared on the forming face of the Golgi complex (Fig. 4). Less electron opaque particles, 70–100 nm in diameter, which seemed to be lipid droplets were contained in the expanded cisterns of lamellae and the vacuoles of the Golgi complex.

The cytoplasm was rich in free ribosomes, a majority of which assembled into ring or lengthwise array, so-called polysomes. Each array was composed of ribosomes from a few to dozens.

The intercellular spaces between adjacent intestinal absorptive cells slightly widened from place to place (Fig. 4). Their enlargement was not so conspicuous as seen in the rat fed with LCT, though it was more prominent than that of the fasted rat. In some enlarged intercellular spaces, a small cluster of a few less electron opaque particles was very rarely observed.

Lipid droplets were hardly seen in the intercellular spaces at the lamina propria (Fig. 5). The central lacteal contained a few lipid particles which were smaller in diameter than the chylomicron observed in the central lacteal during the absorption of LCT (Fig. 5). No alteration was found in the blood capillaries. Lipid particles were never seen in the endothelial cells and the lumen of blood vessels.

Rat fed with LCT: The most striking change in the intestinal absorptive cells after administration of LCT was the occurrence of lipid droplets throughout the cytoplasm, especially prominent at the supranuclear region (Fig. 6). The number and size of lipid droplets varied depending on the location of the absorptive cell at the villus. Absorptive cells along the distal portion of villi showed a pronounced accumulation of lipids.

The microvilli showed no discernible alterations in their dimension or structure. Lipid droplets were not observed at all in the intermicrovillous clefts.

Apical pits which were situated at the bottom of the intermicrovillous clefts did not increase in number and bulk. No lipid droplets were visible within any pits. The number of apical vesicles did not increase. The lipid droplets bounded by a limiting membrane were occasionally seen within the terminal web.

The endoplasmic reticulum showed several outstanding alterations during LCT absorption. Lipid droplets distended the tubules of both the granular and agranular endoplasmic reticulum to be a sphere (Fig. 7, 8). Usually a single lipid droplet was

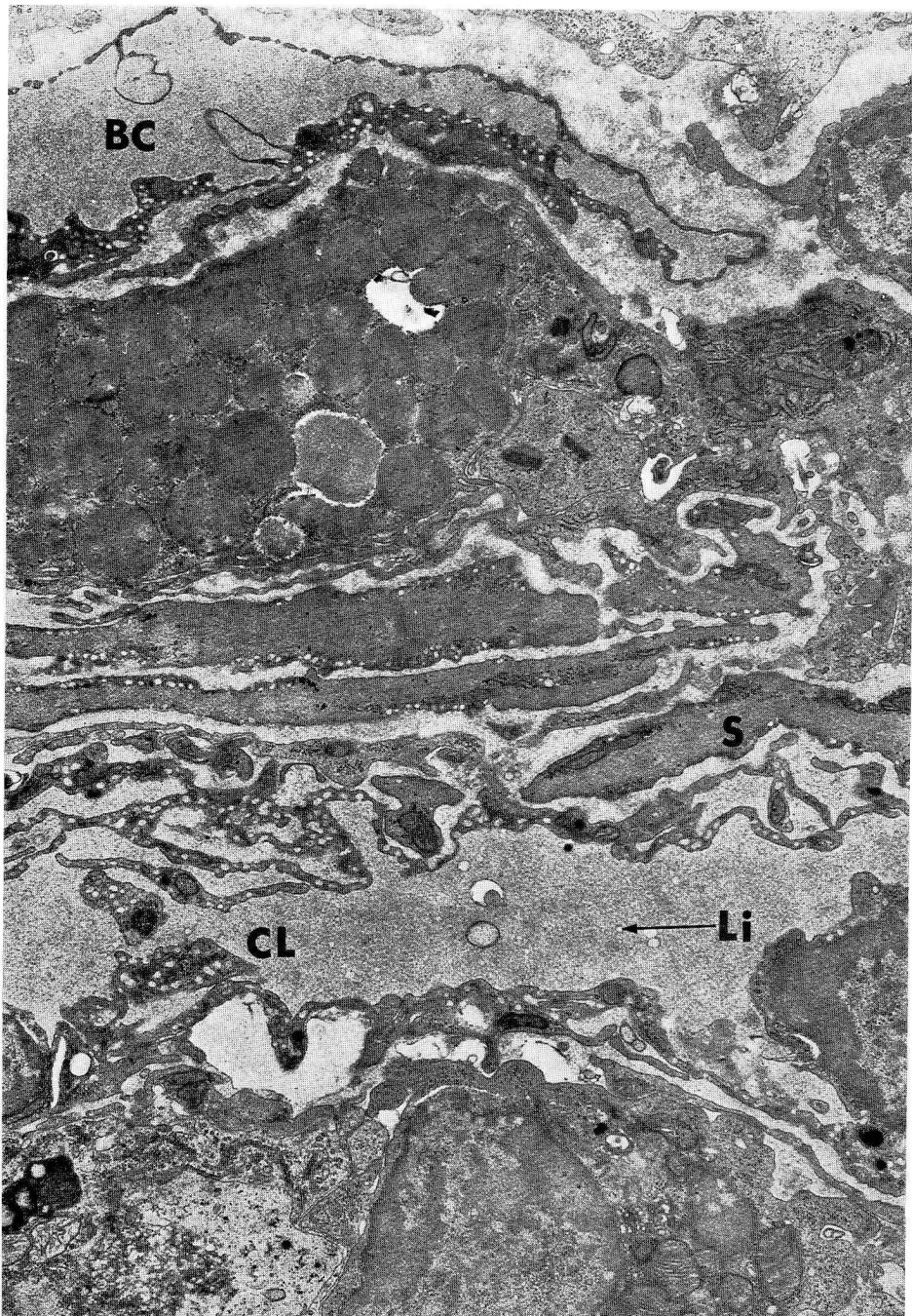


Fig. 5. Lamina propria of intestinal villus from an MCT-fed rat. No lipid droplets are seen in the lumen of the blood capillary (BC). A small number of lipid particles (Li) are observed in the lumen of the central lacteal (CL) and in the intercellular spaces. Smooth muscle cells (S) are seen around the central lacteal. $\times 10,000$

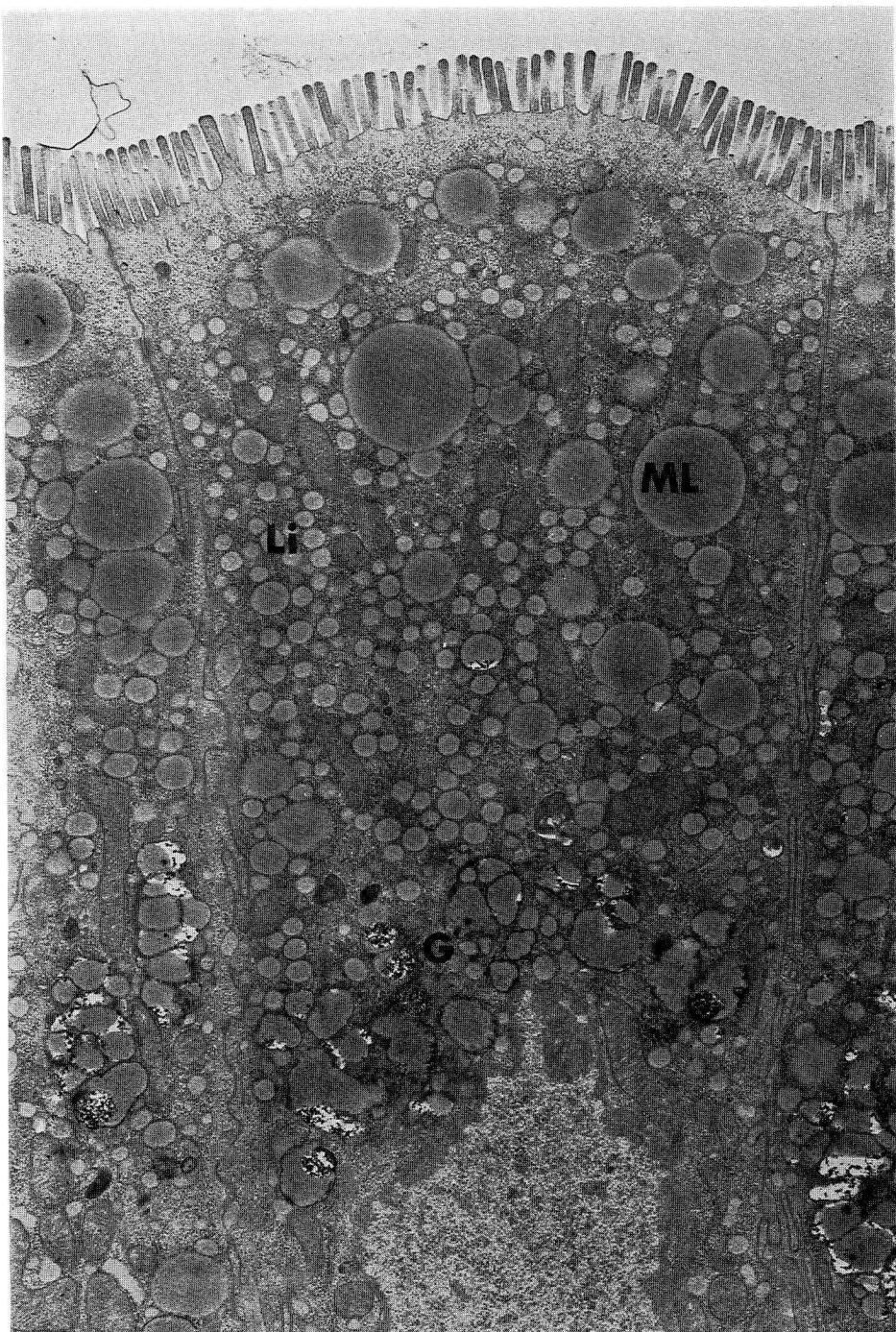


Fig. 6. An absorptive cell during LCT absorption, showing the accumulation of lipid droplets. Two types of lipid droplets, bounded by a limiting membrane (*Li*) and unbounded (*ML*), are seen. The vacuoles of the Golgi complex (*G*) are located in the supranuclear area. $\times 10,000$

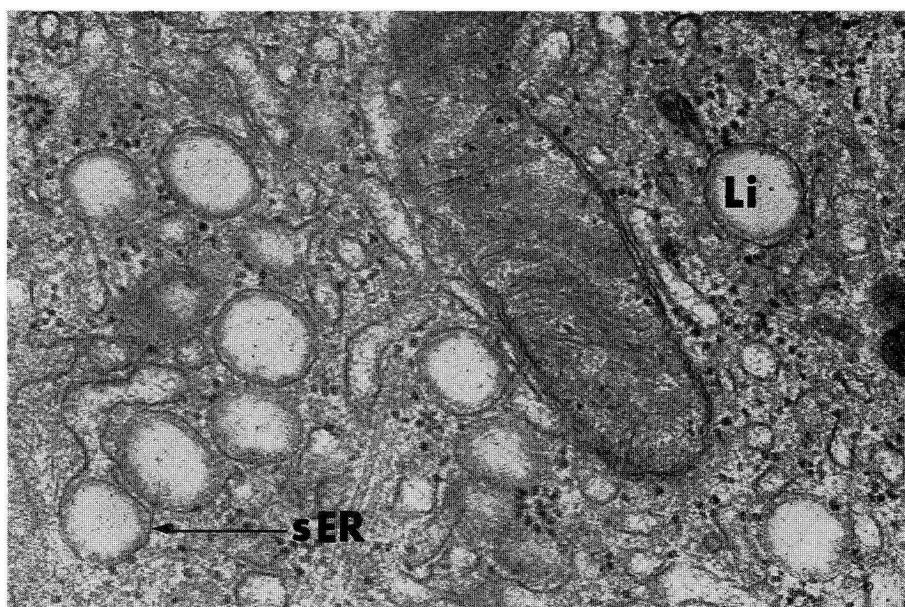


Fig. 7. Apical cytoplasm of an absorptive cell from an LCT-fed rat. Lipid droplets (Li) are enveloped in the agranular endoplasmic reticulum (sER). $\times 62,000$

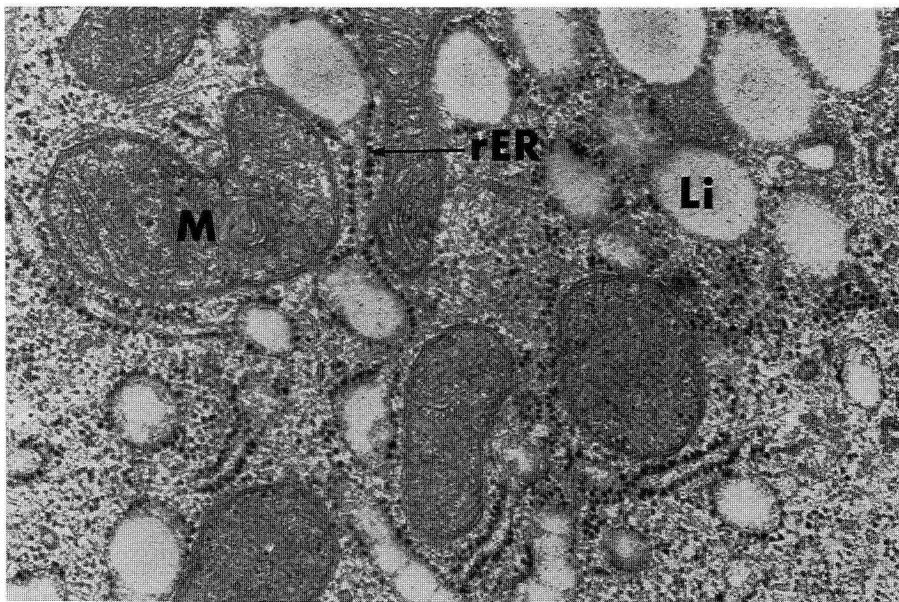


Fig. 8. Middle portion of the cytoplasm of an absorptive cell from an LCT-fed rat. The granular endoplasmic reticulum (rER) contains some lipid droplets (Li). M mitochondria. $\times 34,000$

seen present in the profile of one bulbous expansion of the endoplasmic reticulum, but infrequently two or more lipid droplets were contained in one bulb. Usually the lipid droplets did not fuse with each other in the endoplasmic reticulum. Lipid droplets in the endoplasmic reticulum appeared to be of fairly uniform size, approximately $0.35\text{ }\mu\text{m}$ in diameter. Continuity of the agranular endoplasmic reticulum containing lipid droplets with the granular one was often observed. The more advanced the LCT absorption, the larger the lipid droplets lacking a limiting membrane appeared in the cytoplasm.

The elongated profiles of granular endoplasmic reticulum which were prominent in the cells of the fasted rat diminished greatly in length and number. Free ribosomes increased in the supranuclear cytoplasm. At the early stage of LCT absorption, the Golgi lamellae became reduced in number and length (Fig. 9). The cisterns or vacuoles of the Golgi complex were dilated by accumulation and coalescence of lipid droplets (Fig. 6, 9). Occasionally, the granular endoplasmic reticulum was located in close proximity to the outermost lamella and was devoid of ribosomes on its membrane surface opposite the forming face of the Golgi complex (Fig. 9). As absorption progressed, the Golgi lamellae almost completely disappeared and Golgi vacuoles filled with lipid droplets were conspicuous. Some Golgi vesicles, however, were present in their proper position during fat absorption.

The Golgi vacuoles containing some lipid droplets fused with the lateral cell membrane, and then, the mass of lipid droplets were released into the intercellular spaces (Fig. 6). On occasion, a lipid droplet was also released from the basal surface by exocytosis. The lipid droplets discharged from the cell were devoid of their limiting membrane. A great number of lipid droplets were present in the lowest inter-

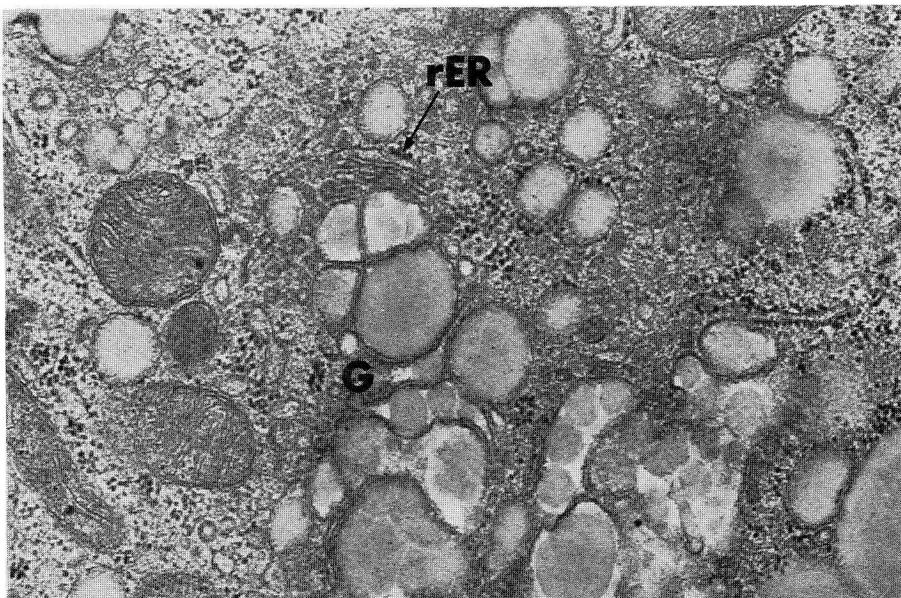


Fig. 9. The Golgi complex (G) of an absorptive cell from an LCT-fed rat. The stacks of the Golgi lamellae are very small. The Golgi vacuoles contain lipid droplets. The granular endoplasmic reticulum (rER) is located in close proximity to the Golgi complex. $\times 35,000$

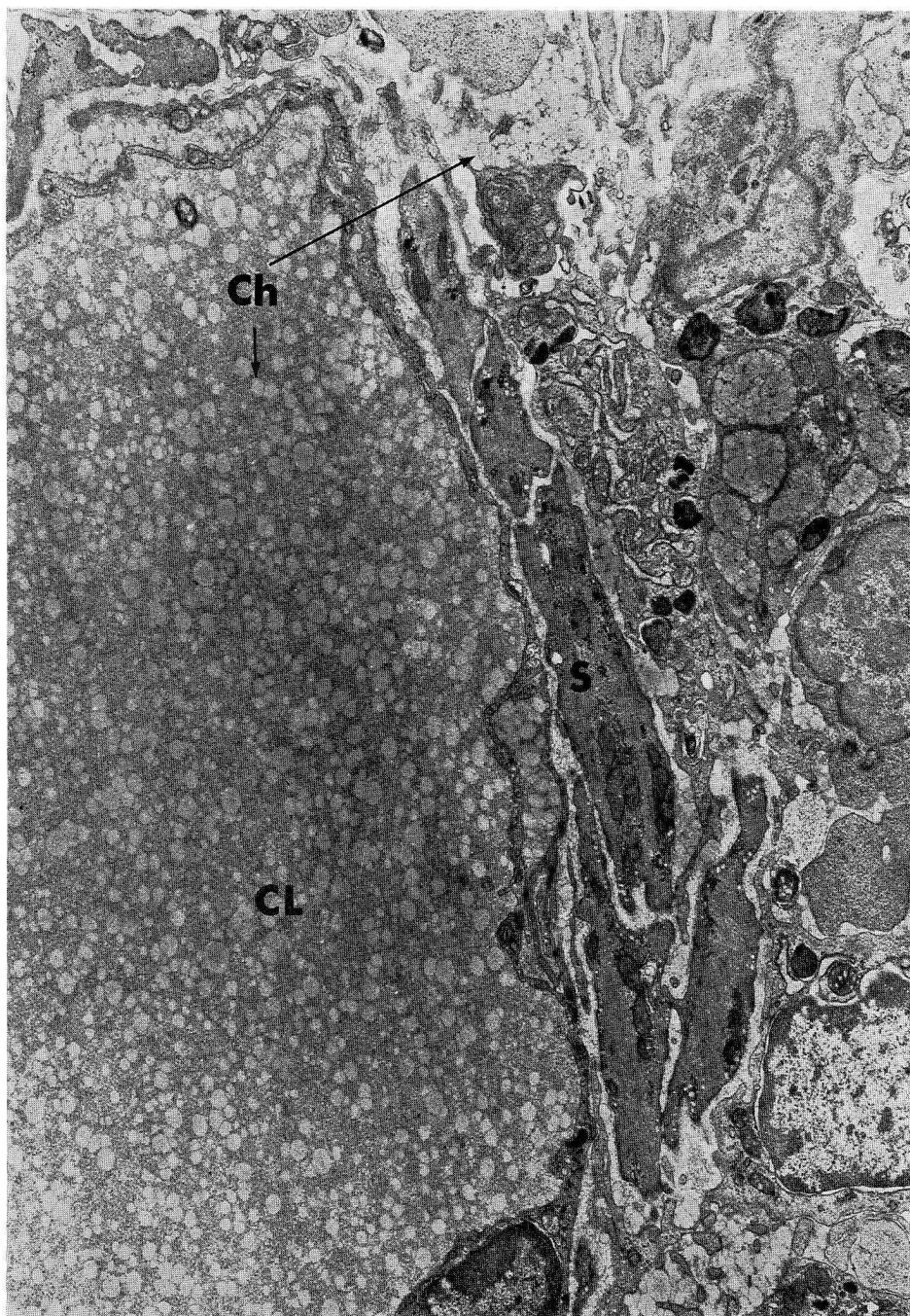


Fig. 10. A central lacteal (CL) in the intestinal villus from an LCT-fed rat. Junctions formed by the endothelial processes open in places. The enlarged spaces contain several chylomicra. Lots of chylomicra (Ch) are seen in the lumen of the central lacteal and in the intercellular spaces of lamina propria. S smooth muscle cell. $\times 9,000$

cellular spaces between absorptive cells.

The intercellular spaces of the lamina propria of the intestinal villus were also filled with lipid droplets (Fig. 10). No lipid particles were seen in blood capillaries, whereas the central lacteal was filled with numerous lipid droplets (Fig. 10). The junctions formed by overlapping of endothelial processes were seen widely open, thus constituting the channel connecting between the lumen of the central lacteal and the intercellular spaces of the lamina propria. The lipid droplets filled these widened intercellular gaps. In the endothelial cells of the central lacteal, numerous small vesicles and small pits which might be either endocytotic or exocytotic in nature could be observed. However, there was no remarkable difference in the number of vesicles or pits among LCT-fed, MCT-fed or fasted rats. Besides the vesicles or pits which did not contain any lipid droplets, some lipid droplets surrounded by a limiting membrane were rarely encountered in the endothelial cytoplasm of the central lacteal.

Discussion

The present study has demonstrated that there are striking morphological differences between the absorption of MCT and LCT. The most conspicuous is that lipid droplets or chylomicra do not appear in the endoplasmic reticulum of the absorptive cells of the MCT-fed rat, whereas a large number of chylomicra appear in the endoplasmic reticulum in the LCT-fed rat.

McKAY et al. (1967) have observed by electron microscopy that a number of lipid droplets as large as chylomicron which occurs in the absorptive cell after feeding of LCT appear in the lumen of the endoplasmic reticulum of the intestinal absorptive cells in the rat fed with MCT. They claim that those droplets correspond to a tiny fraction of MCT reesterified within the endoplasmic reticulum. Their observation is not compatible with the present study in regard to the dimension of lipid particles. The difference may be due to the fatty acid compositions of MCT administered. In the present study, trioctanoin which is the simple triglyceride of octanoic acid (carbon chain length; C: 8) has been used, while McKAY et al. have done an experiment using the compound MCT composed of fatty acids of various carbon chain lengths: hexanoic acid (C: 6), octanoic acid (C: 8) and decanoic acid (C: 10).

In the present study, small particles within the agranular endoplasmic reticulum and the Golgi vacuoles during MCT absorption may represent the resynthesized triglyceride which is known to occur from biochemical investigation (GELB and KESSLER, 1963; SENIOR and ISSELBACHER, 1963; PLAYOUST and ISSELBACHER, 1964; GREENBERGER et al., 1965, 1966; BRINDLEY and HÜBSCHER, 1966; HYUN et al., 1967), although these particles observed in the Golgi vacuoles in fasted and MCT-fed rats are strikingly smaller in diameter than a chylomicron in the rat fed with LCT. From the view point of dimension, however, they come under the category of chylomicron (SCANU and RITTER, 1973).

The endoplasmic reticulum is the structural component of absorptive cells which shows the greatest alteration during fat absorption. During absorption of LCT, the granular endoplasmic reticulum strikingly decreases in the cytoplasm, whereas the agranular endoplasmic reticulum increases at the supranuclear region in the intestinal absorptive cells (PALAY and KARLIN, 1959; CARDELL et al., 1967). CARDELL et al. (1967) have considered that this increase of agranular endoplasmic reticulum is due to being converted from the granular endoplasmic reticulum by detachment of mem-

brane-bound ribosomes. The present study may well support this hypothesis, since a remarkable decrease of granular endoplasmic reticulum in the cytoplasm becomes noticeable in the progress of the absorption of LCT. This seems to be the case even in the absorption of MCT, in which tubular endoplasmic reticulum is increased at the supranuclear area of the absorptive cells. In addition, a frequent occurrence of the continuity between the agranular and the granular endoplasmic reticulum may also suggest that the granular endoplasmic reticulum is involved in active synthesis of the membrane of the agranular endoplasmic reticulum.

As is well known, free fatty acids may be capable of regulating the activity of some enzymes (WEBER et al., 1966, 1967). When a dose of 1.5 ml of octanoic acid is administered to a rat, the intestinal epithelial cells of the upper part of the villi shed into the intestinal lumen (OHSHIMA, unpublished data). These observations support the interpretation that the morphological alterations, which include the vesiculation of microvilli, observed in the absorptive cells during MCT absorption may result from some metabolic alterations of the absorptive cell caused by unesterified octanoic acids.

In the absorption of LCT, the main functions of the agranular endoplasmic reticulum in the absorptive cells are to provide an adequate area for location of the enzymes necessary for triglyceride synthesis (DAWSON and ISSELBACHER, 1960; SENIOR and ISSELBACHER, 1960 and 1962; SJÖSTRAND and BORGSTRÖM, 1967), an intracellular compartment for sequestration of triglycerides and the vesicles involved in the intracellular transport of triglycerides (PALAY and KARLIN, 1959; LACY and TAYLOR, 1962; CARDELL et al., 1967; FRIEDMAN and CARDELL, 1972a, b). In the case of MCT, since only a small fraction of medium chain fatty acids taken up into the absorptive cells is esterified (PLAYOUST and ISSELBACHER, 1964; GREENBERGER et al., 1966), the agranular endoplasmic reticulum increased in the absorptive cells may play a role as an intracellular compartment for sequestration and a channel of the intracellular transport of octanoic acids rather than the metabolic site of MCT or fatty acids.

Intestinal absorptive cells during the absorption of LCT discharge the chylomicra in the Golgi vacuoles into the intercellular spaces by exocytosis at the level of the Golgi complex (WEISS, 1955; PALAY and KARLIN, 1959; LACY and TAYLOR, 1962; CARDELL et al., 1967; FRIEDMAN and CARDELL, 1972a, b). With unesterified medium chain fatty acids, the output takes place through the lateral plasma membrane immediately beneath the junctional complex (CARLIER and BEZARD, 1975), but the intercellular space between adjacent absorptive cells is hardly widened in the present study. These observations may reflect that octanoic acids discharged from the absorptive cells pass downward in the intercellular space between adjacent absorptive cells, pass through the basal lamina without any retention, and enter the lamina propria of the intestinal villi.

The majority of the ingested medium chain triglycerides is transported in the form of unesterified fatty acids by the portal pathway from the site of absorption (HASHIM et al., 1964; GREENBERGER et al., 1966). In the present study, central lacteal during MCT absorption contains a few small lipid particles. This may indicate that the central lacteal is less involved in the absorption of MCT.

In the core of the intestinal villus, it is generally considered that chylomicra enter into the central lacteal through the open gaps of endothelial junctions (CASLEY-SMITH, 1962; LADMAN et al., 1963; HORSTMANN and BREUKER, 1972), while DOBBINS and ROLLINS (1970) have suggested on the basis of their investigations using peroxidase, ferritin

or chylomicron as a tracer that pinocytotic transport may also be very significant for chylomicron transport. The present study, however, is compatible with the opinion of CASLEY-SMITH and other workers.

In the present study, even when the intercellular spaces of the lamina propria of intestinal villi are filled with chylomicra, the area around the blood capillary is devoid of chylomicra. This observation may strongly suggest that there are some factors involving the selection of the transport pathway of chylomicron; however, further study is required in this connection.

中鎖および長鎖トリグリセリド吸収時のラット小腸の電子顕微鏡的研究

大島康史

中鎖トリグリセリド(MCT)の経口投与をうけたラットの小腸吸収細胞の変化を電子顕微鏡を用いて観察し、長鎖トリグリセリド(LCT)の吸収時における変化と比較検討した。

MCT投与では、LCT投与時に出現するカイロミクロロン(直径約 0.35μ)は観察されず、より小さな脂肪滴(直径70-100nm)が小胞体、ゴルジ空胞および中心乳糜管に少數観察された。

これは投与されたMCTの一部のみしか、吸収細胞でトリグリセリドに合成されないと示唆している。

MCT投与時、吸収細胞内に滑面小胞体が著しく増加していた。また粗面小胞体と滑面小胞体の連続、および粗面小胞体の小管状変化がみとめられた。

これらの変化は、MCT吸収によって吸収細胞の代謝機構に何らかの変化がおこったことを示唆するものであろう。

References

- Blomstrand, R.:** Transport form of decanoic acid- 1^{14}C in the lymph during intestinal absorption in the rat. *Acta physiol. scand.* 34: 67-70 (1955).
- Bloom, B., I. L. Chaikoff and W. O. Reinhardt:** Intestinal lymph as pathway for transport of absorbed fatty acids of different chain lengths. *Amer. J. Physiol.* 166: 451-455 (1951).
- Borgström, B.:** Transport form of ^{14}C -decanoic acid in porta and inferior vena cava blood during absorption in the rat. *Acta physiol. scand.* 34: 71-74 (1955).
- Brindley, D. N. and G. Hübscher:** The effect of chain length on the activation and subsequent incorporation of fatty acids into glycerides by the small intestinal mucosa. *Biochim. biophys. Acta* 125: 92-105 (1966).
- Brokerhoff, H. and M. Yurkowski:** Stereospecific analyses of several vegetable fats. *J. Lipid Res.* 7: 62-64 (1966).
- Cardell, R. R. Jr., S. Badenhausen and K. R. Porter:** Intestinal triglyceride absorption in the rat. An electron microscopical study. *J. Cell Biol.* 34: 123-155 (1967).
- Carlier, H. and J. Bezzard:** Electron microscope autoradiographic study of intestinal absorption of decanoic and octanoic acids in the rat. *J. Cell Biol.* 65: 383-397 (1975).

- Casley-Smith, J. R.:** The identification of chylomicra and lipoproteins in tissue sections and their passage into jejunal lacteals. *J. Cell Biol.* 15: 259-277 (1962).
- Dawson, A. M. and K. J. Isselbacher:** The esterification of palmitate-1-C¹⁴ by homogenates of intestinal mucosa. *J. clin. Invest.* 39: 150-160 (1960).
- Dobbins, W. O., III, and E. L. Rollins:** Intestinal mucosal lymphatic permeability: An electron microscopic study of endothelial vesicles and cell junctions. *J. Ultrastr. Res.* 33: 29-59 (1970).
- Friedman, H. I. and R. R. Cardell, Jr.:** Effects of puromycin on the structure of rat intestinal epithelial cells during fat absorption. *J. Cell Biol.* 52: 15-40 (1972a).
- _____: Morphological evidence for the release of chylomicra from intestinal absorptive cells. *Exp. Cell Res.* 75: 57-62 (1972b).
- Gelb, A. M. and J. I. Kessler:** Effect of fatty acid structure on esterification by the small intestine in vitro. *Amer. J. Physiol.* 204: 821-824 (1963).
- Greenberger, N. J., J. J. Franks and K. J. Isselbacher:** Metabolism of 1-C¹⁴ octanoic and 1-C¹⁴ palmitic acid by rat intestinal slices. *Proc. Soc. Exp. Biol. Med.* 120: 468-472 (1965).
- Greenberger, N. J., J. B. Rodgers and K. J. Isselbacher:** Absorption of medium and long chain triglycerides: Factors influencing their hydrolysis and transport. *J. clin. Invest.* 45: 217-227 (1966).
- Hashim, S. A., S. S. Bergen, Jr., K. Krell and T. B. Van Itallie:** Intestinal absorption and mode of transport in portal vein of medium chain fatty acids. *J. clin. Invest.* 43: 1238 (1964).
- Higgins, J. A. and R. J. Barnett:** Fine structural localization of acyltransferases. The mono-glyceride and α -glycerophosphate pathways in intestinal absorptive cells. *J. Cell Biol.* 50: 102-120 (1971).
- Horstmann, E. and H. Breucker:** Über die Lymphkapillaren in den Darmzotten von Meerschweinchen und Affe. *Z. Zellforsch.* 113: 551-557 (1972).
- Hyun, S. A., G. V. Vahouny and C. R. Treadwell:** Portal absorption of fatty acids in lymph- and portal vein-cannulated rats. *Biochim. biophys. Acta* 137:296-305 (1967).
- Kayden, H. J. and M. Medick:** The absorption and metabolism of short and long chain fatty acids in puromycin-treated rats. *Biochim. biophys. Acta* 176: 37-43 (1969).
- Kiyasu, J. Y., B. Bloom and I. L. Chaikoff:** The portal transport of absorbed fatty acids. *J. biol. Chem.* 199: 415-419 (1952).
- Lacy, D. and A. B. Taylor:** Fat absorption by epithelial cells of the small intestine of the rat. *Amer. J. Anat.* 110: 155-185 (1962).
- Ladman, A. J., H. A. Padykula and E. W. Strauss:** A morphological study of fat transport in the normal human jejunum. *Amer. J. Anat.* 112: 389-419 (1963).
- McKay, D. G., H. Kaunitz, I. Csavossy and R. E. Johnson:** Electron microscope studies of the absorption of lipids. II. Medium chain saturated triglycerides. *Metabolism* 16: 127-136 (1967).
- Palay, S. L. and L. J. Karlin:** An electron microscopic study of the intestinal villus. II. The pathway of fat absorption. *J. biophys. biochem. Cytol.* 5: 373-383 (1959).
- Playoust, M. R. and K. J. Isselbacher:** Studies on the intestinal absorption and intramucosal lipolysis of a medium chain triglyceride. *J. clin. Invest.* 43: 878-885 (1964).
- Scanu, A. M. and M. C. Ritter:** The proteins of plasma lipoproteins: Properties and significance. *Adv. clin. Chem.* 16: 111-151 (1973).
- Senior, J. R. and K. J. Isselbacher:** Activation of long-chain fatty acids by rat-gut mucosa. *Biochim. biophys. Acta* 44: 399-400 (1960).
- _____: Direct esterification of monoglycerides with palmitoyl Coenzyme A by intestinal epithelial subcellular fractions. *J. biol. Chem.* 237: 1454-1459 (1962).
- _____: Demonstration of an intestinal monoglyceride lipase: An enzyme with a possible role in the intracellular completion of fat digestion. *J. clin. Invest.* 42: 187-195 (1963).
- Sjöstrand, F. S. and B. Borgström:** The lipid components of the smooth-surfaced membrane-

- bounded vesicles of the columnar cells of the rat intestinal epithelium during fat absorption. *J. Ultrastr. Res.* 20: 140-160 (1967).
- Strauss, E. W.:** Electron microscopic study of intestinal fat absorption in vitro from mixed micelles containing linolenic acid, monoolein, and bile salt. *J. Lipid Res.* 7: 307-323 (1966).
- Valdivieso, V. D. and A. D. Schwabe:** Factors influencing the absorption of a medium chain triglyceride. I. The role of bile in the intraluminal phase of absorption. *Gastroenterology* 48: 331-335 (1965a).
-
- : Factors influencing the absorption of a medium chain triglyceride. II. The role of pancreatic juice in the intraluminal phase of absorption. *Gastroenterology* 48: 336-341 (1965b).
- Weber, G., H. J. H. Convery, M. A. Lea and N. B. Stamm:** Feedback inhibition of key glycolytic enzymes in liver: Action of free fatty acids. *Science* 154: 1357-1360 (1966).
- Weber, G., M. A. Lea, H. J. H. Convery and N. B. Stamm:** Regulation of glycogenesis and glycolysis: Studies of mechanisms controlling enzyme activity. *Adv. Enzyme Regulation* 5: 257-298 (1967).
- Weiss, J. M.:** The role of the Golgi complex in fat absorption as studies with the electron microscope with observations on the cytology of duodenal absorptive cells. *J. exp. Med.* 102: 775-782 (1955).

大島 康史
〒812福岡市東区馬出3-1-1
九州大学医学部
解剖学教室

Dr. Yasufumi OHSHIMA
Department of Anatomy
Kyushu University Faculty of Medicine
3-1-1 Maedashi, Higashi-ku
Fukuoka, 812 Japan