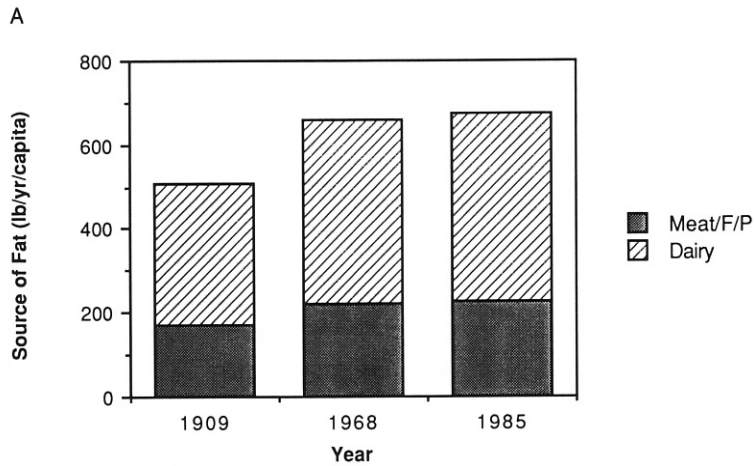


ANSC/NUTR 618
LIPIDS & LIPID METABOLISM
Sources and Digestion of Dietary Fat

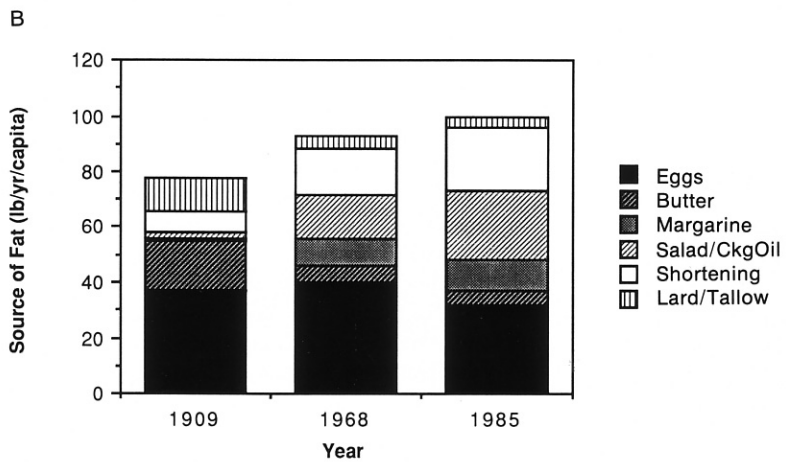
I. Sources of dietary fat in humans

A. Trends in consumption from 1909

1. Consumption of the combination of meat, fish, and poultry was stable over time, although poultry replaced red meat consumption.



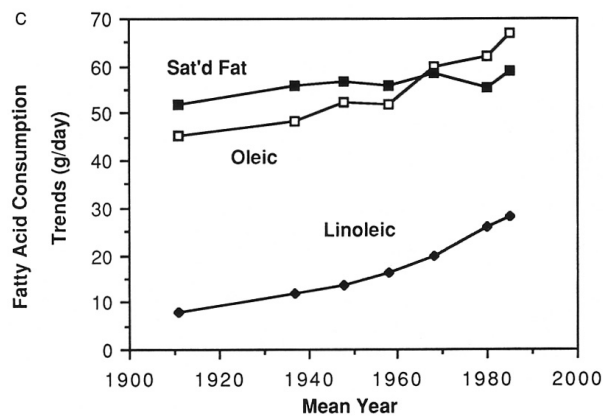
2. Consumption of eggs, lard, tallow, and butter declined, but oil consumption increased.



3. Consumption of oils and shortening (*trans*-fats) increased.

4. Oleic acid and linoleic acid consumption has increased

5. Saturated fat consumption is stable.



B. Composition of dietary fats

1. Plant oils are high in unsaturated fatty acids, but contain no cholesterol.
2. Animal fats are high in saturated fatty acids and contain cholesterol.
3. Fish oils are high in 20:5 and 22:6 and can be high in cholesterol.



Dietary Fat

Fatty acid content normalized to 100 percent

Canola oil	0	6%	22%	10%	62%
Safflower oil	0	10%	77%	Trace	13%
Sunflower oil	0	11%	69%		20%
Corn oil	0	13%	61%	1%	25%
Olive oil	0	14%	8%	1%	77%
Soybean oil	0	15%	54%	7%	24%
Peanut oil	0	18%	33%		49%
Margarine	0	19%	30%	2%	49%
Cottonseed oil	0	27%	54%		19%
Vegetable shortening	0	28%	26%	2%	44%
Chicken fat	11	31%	21%	1%	47%
Lard	12	41%	11%	1%	47%
Precreamed/ meat fat shortening	9	45%	6%	1%	48%
Beef fat	14	52%	3%	1%	44%
Butter (fat)	33	66%	2%	2%	30%

Salmon oil / 35 / Cholesterol 20% / 5% / 5% / SFA LA ALA EPA + DHA 35% / MUFA 35% /

C. Composition of fats in animal feeds

1. Most plants are low in total fat and high in 18:1 and/or 18:2n-6.
2. Oil seeds are very high in fat, and flax seed contains around 30% 18:3n-3.
3. Grains provide most of the fat in animal diets unless they receive fat supplements.

Table 20.2. The fatty acid composition of some typical feedstuffs

	Fatty acids (%)	Fatty acid content (g/100g FA)									
		14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:0	20:1	22:1
Cereals											
Barley	1.6	—	27.6	0.9	1.5	20.5	43.3	4.3	—	—	—
Maize	3.2	T ^a	16.3	—	2.6	30.9	47.8	2.3	—	—	—
Milo	2.3	—	20.0	5.2	1.0	31.6	40.2	2.0	—	—	—
Oats	3.2	T	22.1	1.0	1.3	38.1	34.9	2.1	—	—	—
Wheat	1.0	T	20.0	0.7	1.3	17.5	55.8	4.5	—	—	—
By-products											
Gluten meal	1.3	—	17.2	0.9	0.8	26.7	53.0	1.4	—	—	—
Distillers' grains	10.5	—	15.6	—	2.7	24.2	54.5	1.8	—	—	—
Forages											
Citrus pulp	2.7	—	32.1	3.9	1.8	23.8	36.7	1.8	—	—	—
Dehydrated alfalfa meal (17%)	1.4	0.7	28.5	2.4	3.8	6.5	18.4	39.0	—	—	—
Cocksfoot	—	1.4	11.2	6.4	2.6	—	76.5	—	—	—	—
Perennial ryegrass	—	T	11.9	1.7	2.2	14.6	68.2	—	—	—	—
Pasture grass	—	1.1	16.0	2.5	2.0	3.4	13.2	61.3	T	—	—
Red clover	—	1.5	14.2	—	3.7	—	5.6	72.3	—	—	—
White clover	—	1.1	6.5	2.5	0.5	6.6	18.5	60.7	2.0	—	—
Oil seeds											
Cottonseed	18.6	0.8	25.3	—	2.8	17.1	53.2	T	T	—	—
Rape (Tower)	38.0	—	4.3	T	1.7	59.1	22.8	8.2	1.0	—	0.9
Rape (Target)	38.0	—	3.3	T	1.5	21.4	14.2	7.0	0.7	12.3	38.9
Soybean	18.0	T	10.7	T	3.9	22.8	50.8	6.8	T	—	—
Sunflower	34.7	T	5.5	—	3.6	21.7	68.5	T	T	—	—

Source: Modified from Palmquist, 1988.

^aValue less than 0.5%.

D. Composition of fat supplements

1. Animal/vegetable blends are common, especially for studies that use laboratory species.
2. Coconut oil is especially high in 8:0, 10:0, 12:0, and 14:0.
3. Olive oil contains some 20:4, 20:5, and 22:6.

Table 20.3. The fatty acid composition of some typical fat supplements

Supplement	Fatty acid content (g/100 g FA)												Iodine value ^a	
	8:0	10:0	12:0	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:4	20:5		22:6
Animal-vegetable blend	—	1.3	3.5	2.2	23.8	1.6	16.8	31.7	14.9	1.7	—	—	—	60
Beef tallow	—	—	—	3.0	25.8	6.1	18.8	39.7	4.5	1.0	—	—	—	50
Coconut oil	10.0	9.8	39.8	15.0	12.3	—	3.4	8.5	1.2	—	—	—	—	10
Peanut oil	—	—	—	—	11.5	—	3.0	53.0	26.0	—	—	—	—	90
Lard	—	—	—	0.9	24.4	6.5	10.6	38.4	19.3	—	—	—	—	65
Menhaden oil	—	—	—	11.9	23.2	16.4	5.6	15.3	2.7	1.9	—	—	—	160
Olive oil	—	—	—	—	13.0	1.0	2.5	74.0	9.0	1.5	1.6	11.5	7.6	85
Palm oil	—	—	—	1.5	42.0	—	4.0	43.0	9.5	—	—	—	—	50
Palm kernel oil	2.5	5.0	48.5	17.5	10.5	—	1.5	12.5	2.0	—	—	—	—	17
Safflower oil	—	—	—	—	8.0	—	3.0	13.5	75.0	0.5	—	—	—	140

Source: Palmquist, 1988.

^aValues are a standard measure of unsaturation.

II. Dietary sources of cholesterol

FOODS	CHOLESTEROL (mg)
Fruits/vegetables/grains	0
Milks (1 cup serving)	
Whole milk	33
Low-fat milk	22
Skim milk	4
Yogurt	30
Low-fat yogurt	14
Cheeses (1 oz serving)	
Cheddar	30
American processed	27
Swiss	26
Ice creams and puddings (1/2 cup serving)	
Ice cream	29
Pudding	15
Spreads (1 tsp)	
Butter	11
Margarine (all-vegetable)	0
Creams (1 tsp)	
Whipping	20
Sour	6
Half & Half	6
Meats (3 oz serving)	
Veal cutlet	100
Lamb chop	83
Pork chop	83
Chicken	70
Beef steak	70
Hot dogs	43
Organ meats (3 oz serving)	
Brain	1,696
Liver	410
Kidneys	329
Eggs (1 large egg)	
Yolk	213
White	0
Seafood (3 oz serving)	
Shrimp	166
Lobster	61
Fish fillets	54
Oysters	47

III. Intake and initial processing of dietary fats

A. Intake of cholesterol and fat in three human populations

Item	Older men	Men	PM women
Age, <i>yr</i>	49	36	58
Body weight, <i>kg</i>	86	86	71
LDL cholesterol, <i>mg/dL</i>	143	122	124
HDL cholesterol, <i>mg/dL</i>	41	47	62
Triacylglycerols, <i>mg/dL</i>	205	102	92
Total energy intake, <i>kcal</i>	2,293	2,085	1,633
Cholesterol, <i>mg/d</i>	276	353	202
Saturated fat, <i>g/d</i>	28	39	20
Monounsaturated fat, <i>g/d</i>	29	26	15
Polyunsaturated fat, <i>g/d</i>	14	10	8
Total fat, <i>g/d</i>	92	87	62

B. Initial digestion of dietary fats

1. Saliva of rats (not humans) contains lingual lipase, which digests milk fats.

- a. Primary products – 2,3-diacylglycerols
- b. pH optimum – 4.5 - 5.4, so lingual lipase is active in the stomach
- c. Does not require bile salts for activity.
- d. ***Lingual lipase probably does not exist in human infants.***

2. Lipase from human breast milk, bile salt-stimulated lipase, is taken up by human infants and activated by bile salts in the small intestine.

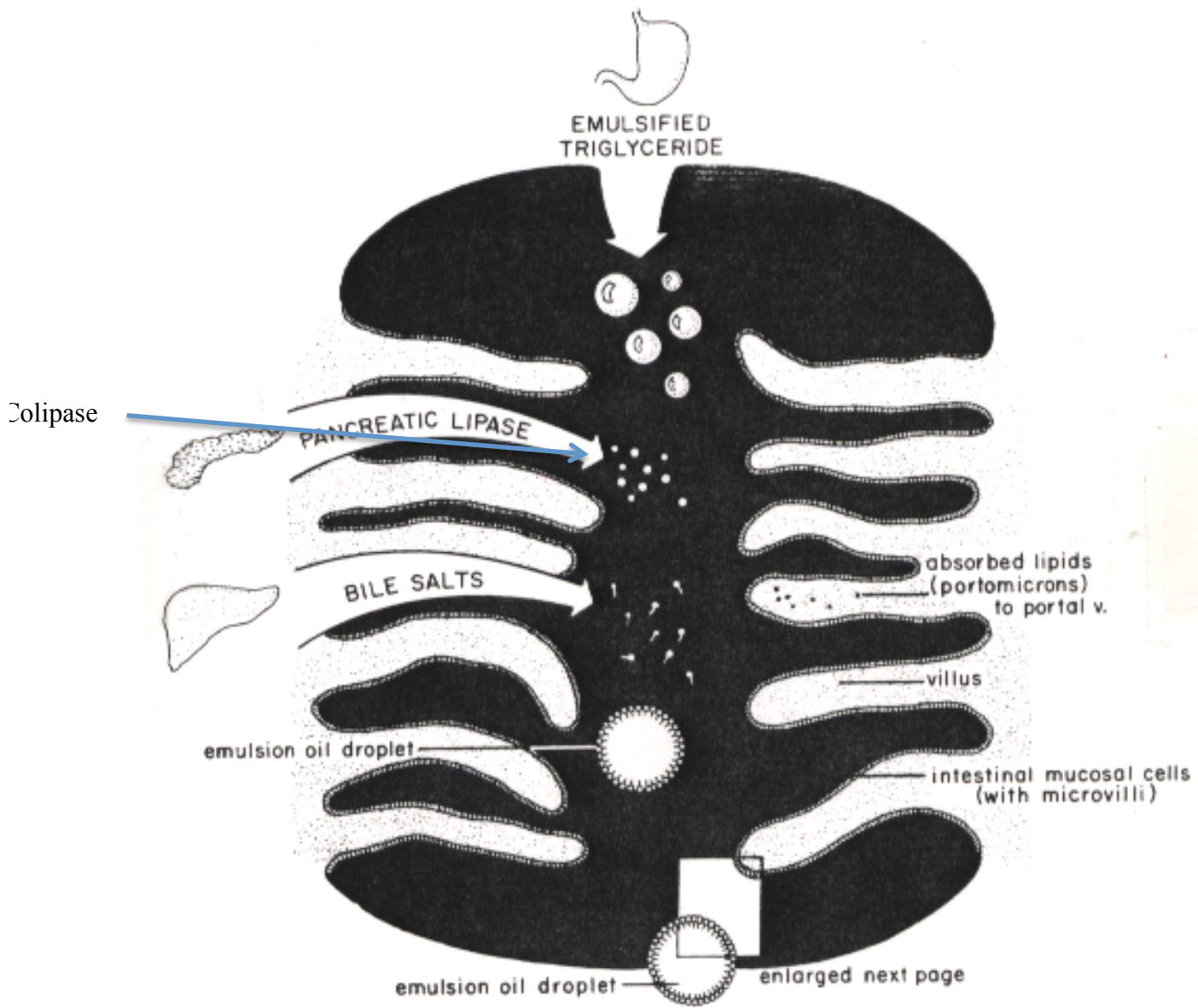
C. Digestion of fat in the stomach

1. Stomach causes physical reduction in fat particle size.
2. Gastric lipase
 - a. Responsible for up to 25% of TAG hydrolysis in adults and ***infants***.
 - b. pH optimum around 4.0.

IV. Digestion of fats in the small intestine

A. Secretion of cholecystokinin from the intestinal mucosal cells (stimulated by fat in the intestine) causes:

1. Gall bladder contraction.
 - a. The gall bladder contains 40 to 70 mL.
 - b. The gall bladder releases approximately 700 mL/d (extensive recirculation).



2. Secretion of pancreatic digestive enzymes (approximately 1,200 mL/d).

a. Pancreatic lipase

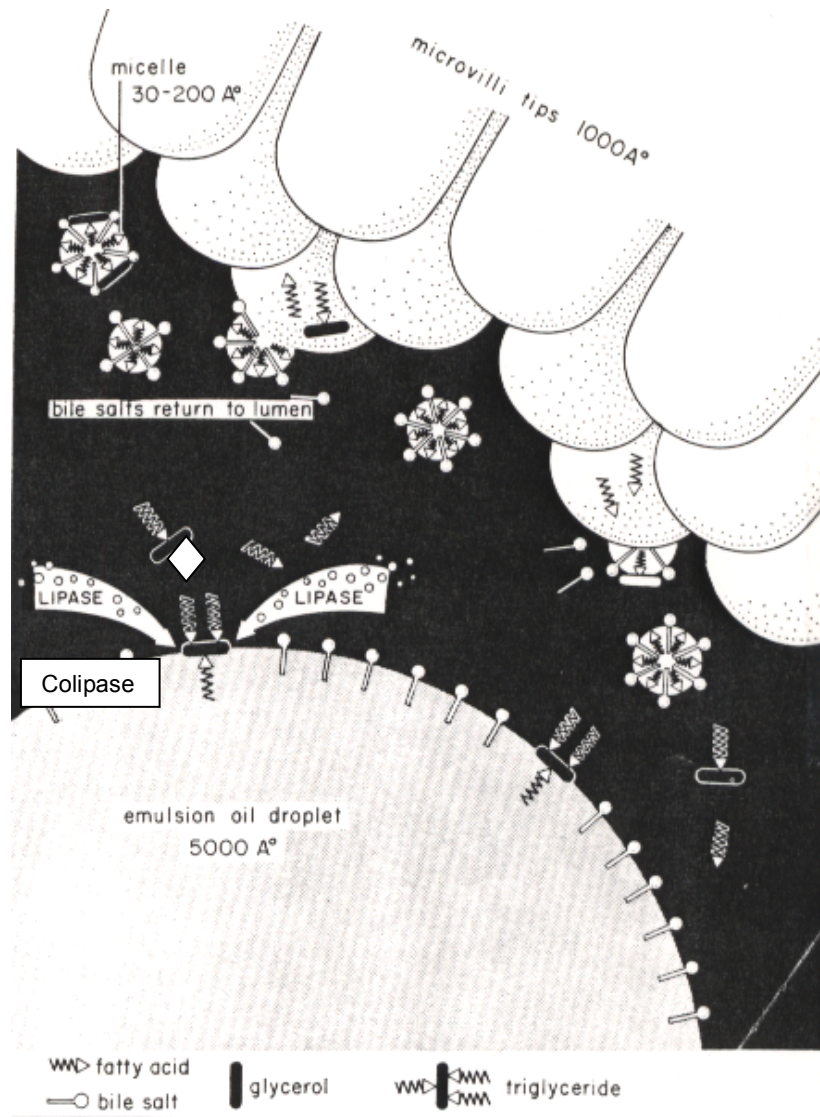
b. Colipase (activates lipase in the presence of bile salts)

B. Functions of bile acids

1. Emulsification of fats, leading to increased surface area of fats.

2. Activation of pancreatic lipase (at low concentrations).

3. Formation of mixed micelles.



C. Emulsification by bile salts

1. Bile acids and glycine or taurine conjugates serve as detergents.
2. Bile salts cause the formation of triacylglycerol particles of 1 μm or less (which greatly increases surface area).
3. Other emulsifiers: phospholipids (especially lysolecithin [lysophosphatidyl choline]) and 2-monoacylglycerols.

D. Hydrolysis of dietary fat by pancreatic lipase

1. Pancreatic lipase works at lipid-water interface.
2. Pancreatic lipase is activated by bile salts at low concentrations.
3. Inhibited by bile salts at high concentrations.
4. Co-lipase:

- a. Secreted by pancreas with lipase.
 - b. Binds to bile salt micelles.
 - c. Reduces inhibitory action of bile salts on pancreatic lipase.
5. Pancreatic lipase hydrolyzes TAG to fatty acids and 2-monoacylglycerol (**2-MAG**).

V. Absorption from small intestine

A. Formation of mixed micelles

1. Mixed micelles *are not small chylomicrons*.
2. Mixed micelles are 4-6 nm in diameter.
3. Formed when bile salts and fatty acids reach a critical micellar concentration (2 – 5 mM for bile salts).
4. Mixed micelles incorporate 2-MAGs, lysolecithin, cholesterol, and long-chain fatty acids.

B. Absorption into the enterocytes (intestinal mucosal cells).

1. 2-MAG, lyso-phospholipids, FAs, and cholesterol dissociate at the surface of the mucosal cells.
2. Produce locally high concentrations of 2-MAG, lyso-phospholipids, and fatty acids.
3. These are absorbed by the epithelial cells of the *duodenum* and *proximal jejunum*.

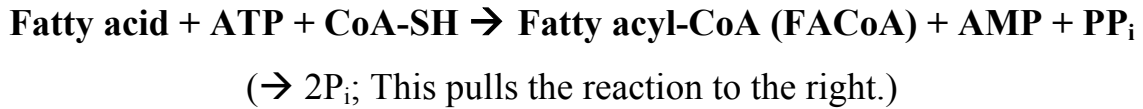
C. Bile salts

1. Bypass the duodenum and jejunum.
2. Bile salts are reabsorbed almost entirely in the ileum (*water soluble*).

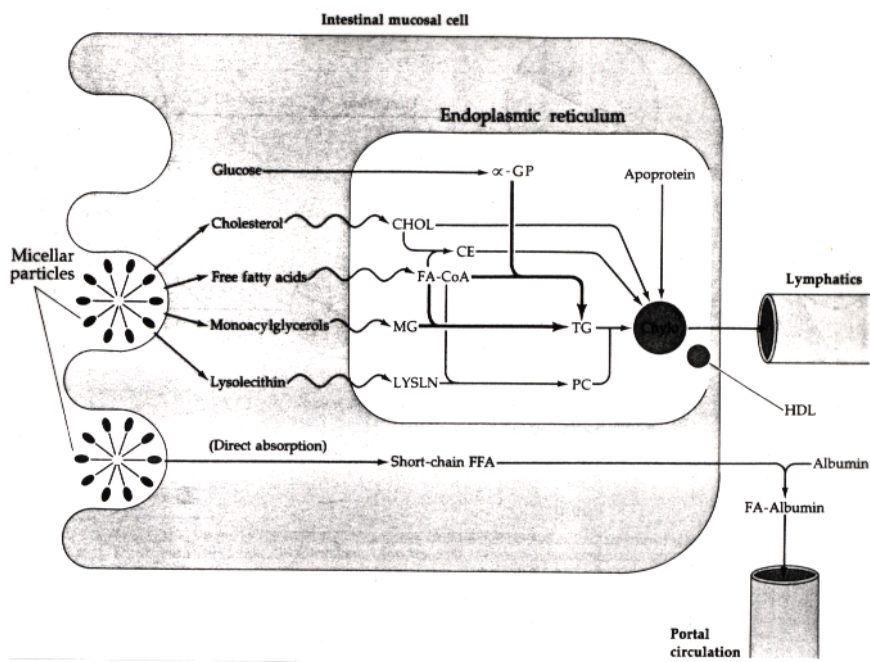
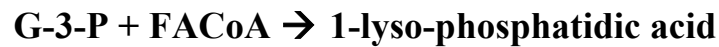
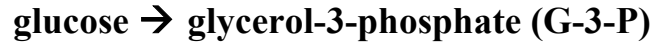
VI. Synthesis of TAG and phospholipids in enterocytes

A. Triacylglycerols

1. 75% of TAGs are synthesized via the 2-monoacylglycerol pathway *located on the smooth endoplasmic reticulum*.



2. 25% of TAGs are synthesized via the standard TAG biosynthetic pathway *located on the rough endoplasmic reticulum*.



B. Phospholipids

1. Phosphatidylcholine (lecithin)



2. Others – Phosphatidylethanolamine, phosphatidyl serine

C. Cholesterol esters: $\text{Cholesterol} + \text{FACoA} \rightarrow \text{Cholesterol ester}$

VII. Chylomicrons

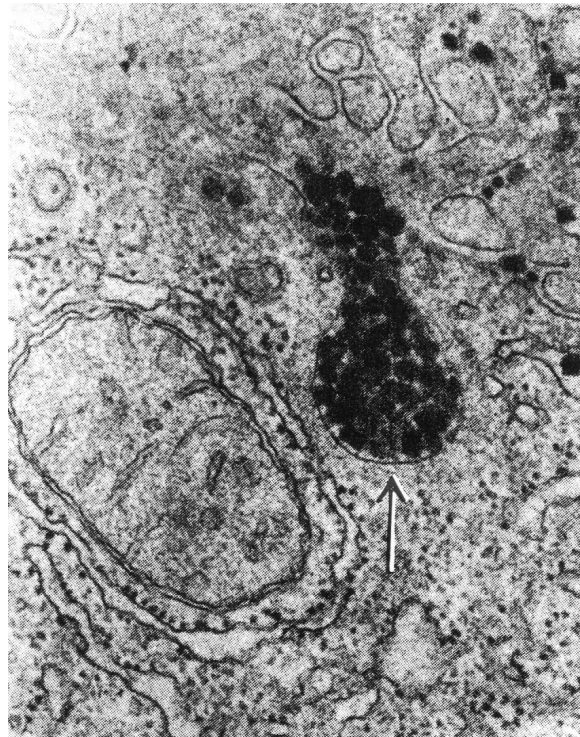
A. Synthesis

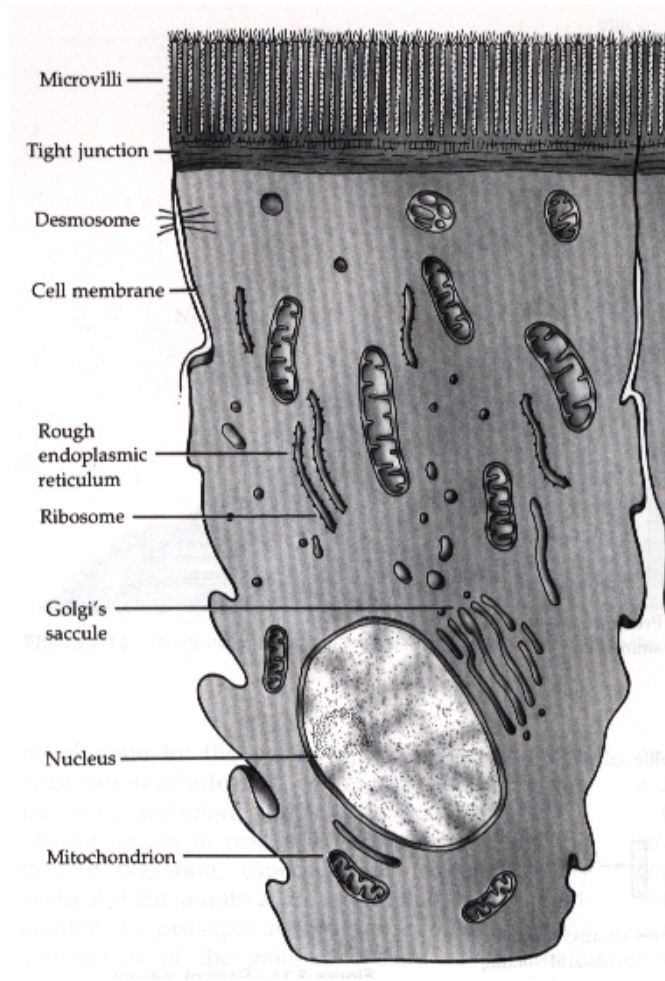
1. Lipid droplets form within the endoplasmic reticulum and Golgi apparatus.
2. Lipid droplets contain TAG, phospholipid, cholesterol, cholesterol ester, and apolipoprotein (with carbohydrate) complexes.
 - a. Apolipoproteins and phospholipids are formed in the rough endoplasmic reticulum.
 - b. TAG are formed in the smooth endoplasmic reticulum and are transferred to ApoB₄₈ to form a developing core for the chylomicron.
 - c. After accumulating TAG and CE, Golgi vesicles form and carbohydrate moieties are added to the apolipoproteins.
2. Golgi vesicles fuse with the cell membrane and are extruded into the lacteals.
3. Chylomicrons are transported via the lymphatics to the subclavian vein.

B. Composition

- 70 – 90% TAG
- 4 – 8% phospholipid
- 3% cholesterol
- 4% cholesterol ester
- 2% protein (apolipoprotein B)

(The figure at right is actually a micrograph of liver, showing subcellular structures and lipoprotein particles (VLDL), which are similar to chylomicrons.)





VIII. Cholesterol absorption

A. Sources of cholesterol in the small intestine

1. **Dietary:** In humans, this accounts for 0.4 - 0.5 g/d.
2. **Biliary:** 20 to 30 g bile salts enter the small intestine daily (4 to 5 g are recycled 5 to 6 times). Also, cholesterol and cholesterol ester enter the small intestine via the bile.
3. **Intestinal mucosa:** A minor contributor to total cholesterol intake.
4. **Ruminal microflora:** A minor contributor to total cholesterol intake in sheep and cattle.

B. Mechanism of absorption from the small intestine

1. Cholesterol esters are hydrolyzed by pancreatic cholesterol esterases.
2. Free cholesterol is incorporated into mixed micelles. (In the absence of bile acids cholesterol absorption is negligible.)
3. Free cholesterol is absorbed into the intestinal mucosal cells and re-esterified to form cholesterol esters.

C. Sources of loss of cholesterol from the dietary tract

1. Bile salts

- 0.8 g/d bile salts are lost in the feces.
- The remainder (98 - 99%) is taken up in the ileum (enterohepatic circulation).

2. Cholesterol: cholesterol is poorly absorbed.

- Approximately 0.4 g/d lost in the feces
- Only 30 to 60% dietary plus biliary cholesterol absorbed.
- Increased cholesterol intake results in a **greater amount** of cholesterol absorbed, but a **lesser percentage** absorbed.

3. Plant sterols

- 200 to 300 mg/d are ingested.
- Plant sterols are absorbed only in trace amounts.
- In large amounts, plant sterols inhibit cholesterol absorption (mechanism unknown).

4. 0.2 to 0.4 g/d of cholesterol is lost as sloughed skin.

