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.

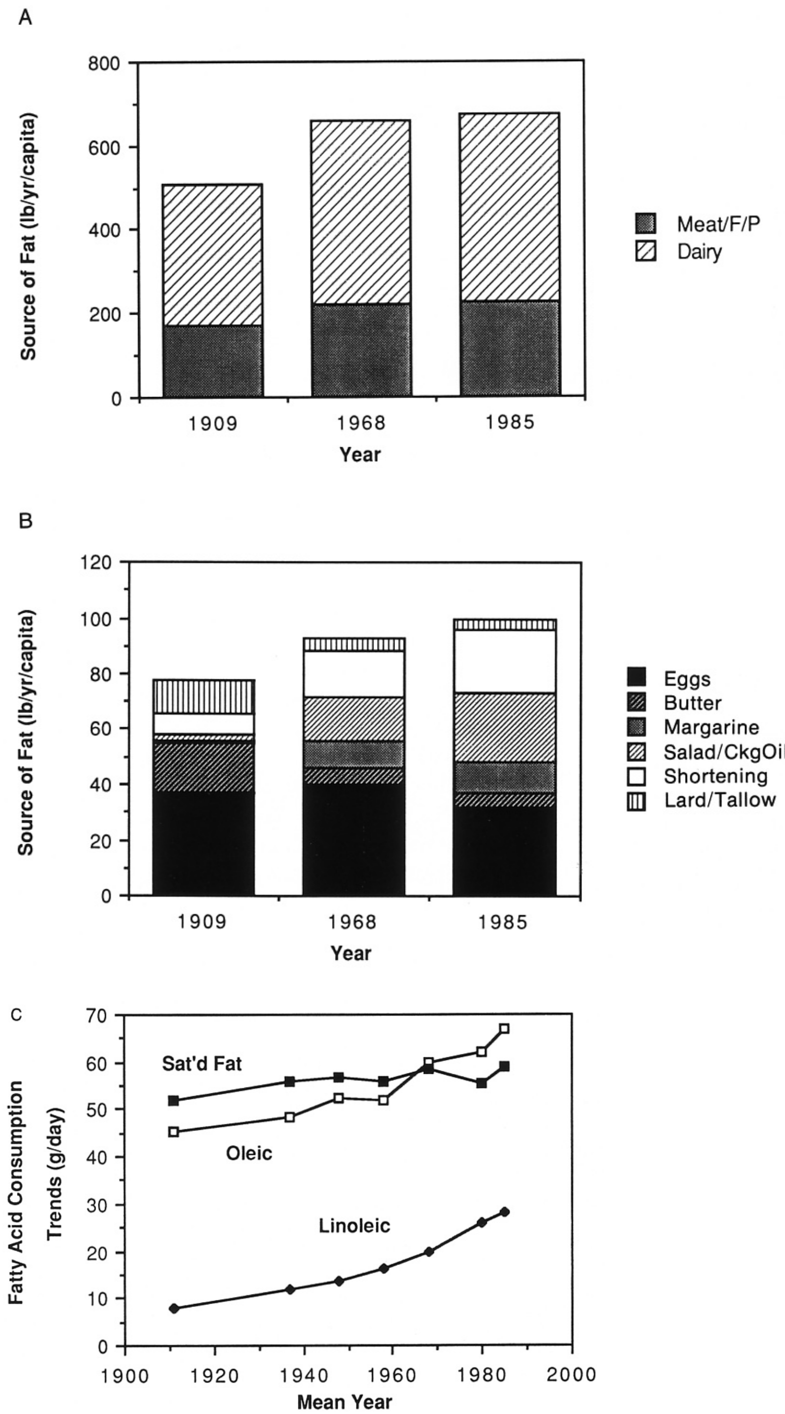
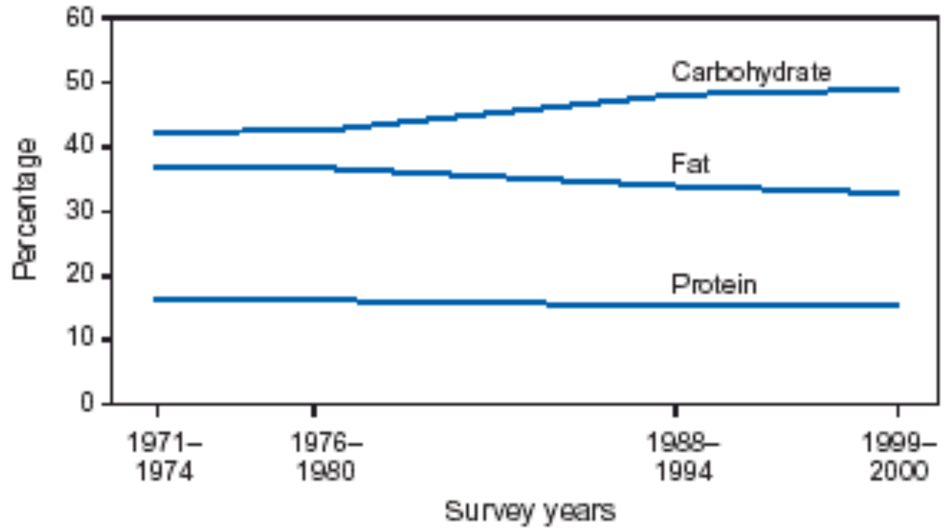
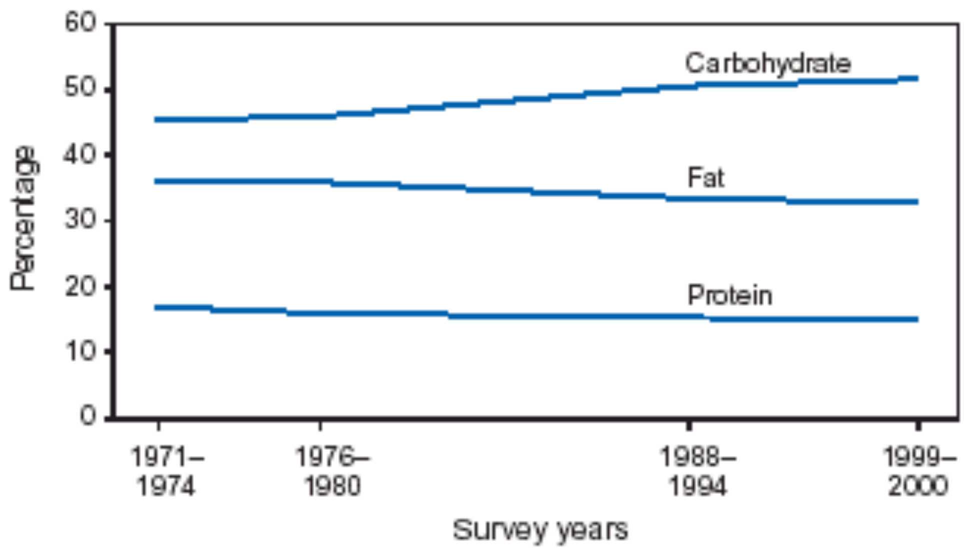


FIGURE 1. Percentage of kilocalories from macronutrient intake among men aged 20–74 years*, by survey years — National Health and Nutrition Examination Surveys (NHANES), United States, 1971–2000



*Age adjusted by direct standardization to the 2000 U.S. Census population by using age groups 20–39, 40–59, and 60–74 years.

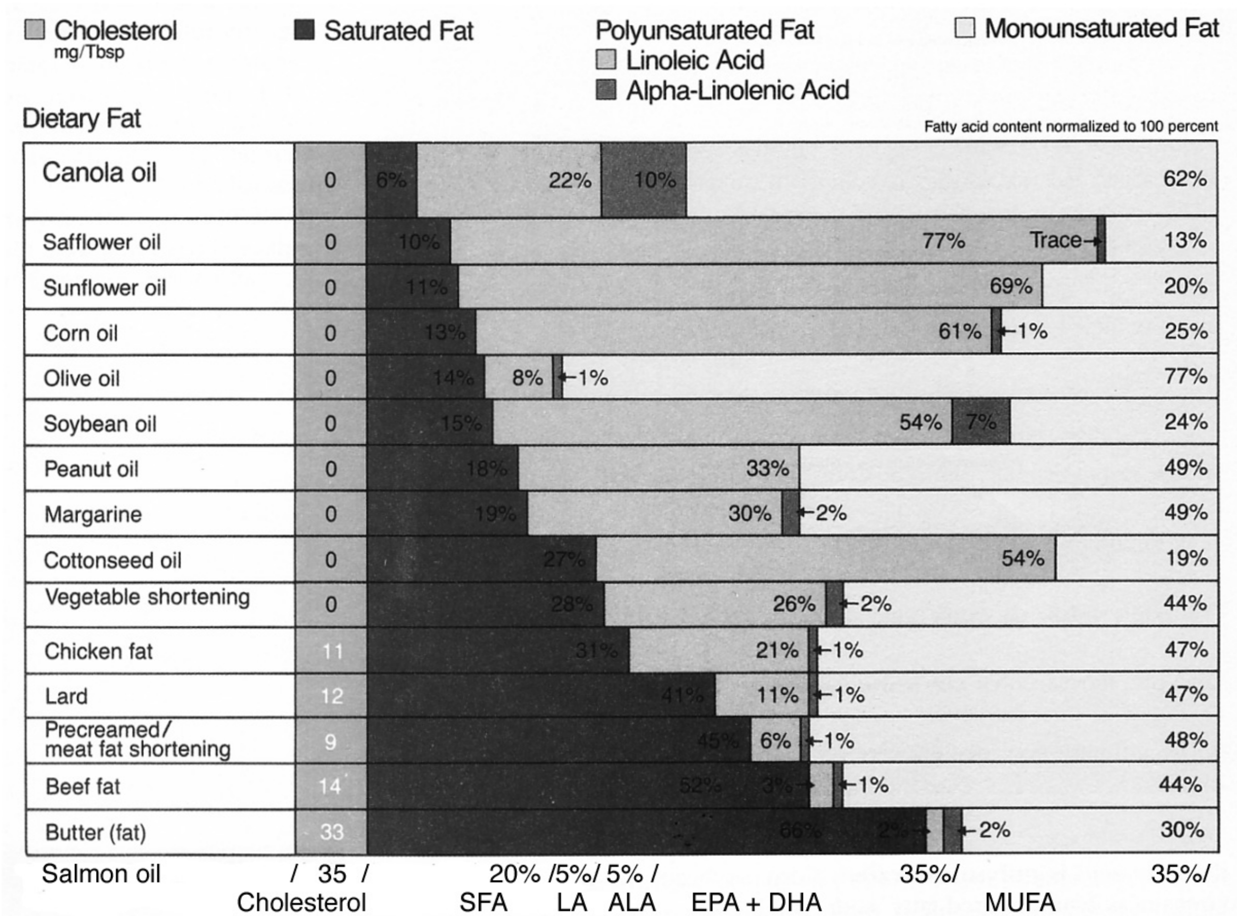
FIGURE 2. Percentage of kilocalories from macronutrient intake among women aged 20–74 years*, by survey years — National Health and Nutrition Examination Surveys (NHANES), United States, 1971–2000



*Age adjusted by direct standardization to the 2000 U.S. Census population by using age groups 20–39, 40–59, and 60–74 years.

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.



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.
[a]Value 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) 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	Iodine value[a]
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.
[a]Values 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, *yr*	49	36	58
Body weight, *kg*	86	86	71
LDL cholesterol, *mg/dL*	143	122	124
HDL cholesterol, *mg/dL*	41	47	62
Triacylglycerols, *mg/dL*	205	102	92
Total energy intake, *kcal*	2,293	2,085	1,633
Cholesterol, *mg/d*	276	353	202
Saturated fat, *g/d*	28	39	20
Monounsaturated fat, *g/d*	29	26	15
Polyunsaturated fat, *g/d*	14	10	8
Total fat, *g/d*	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.

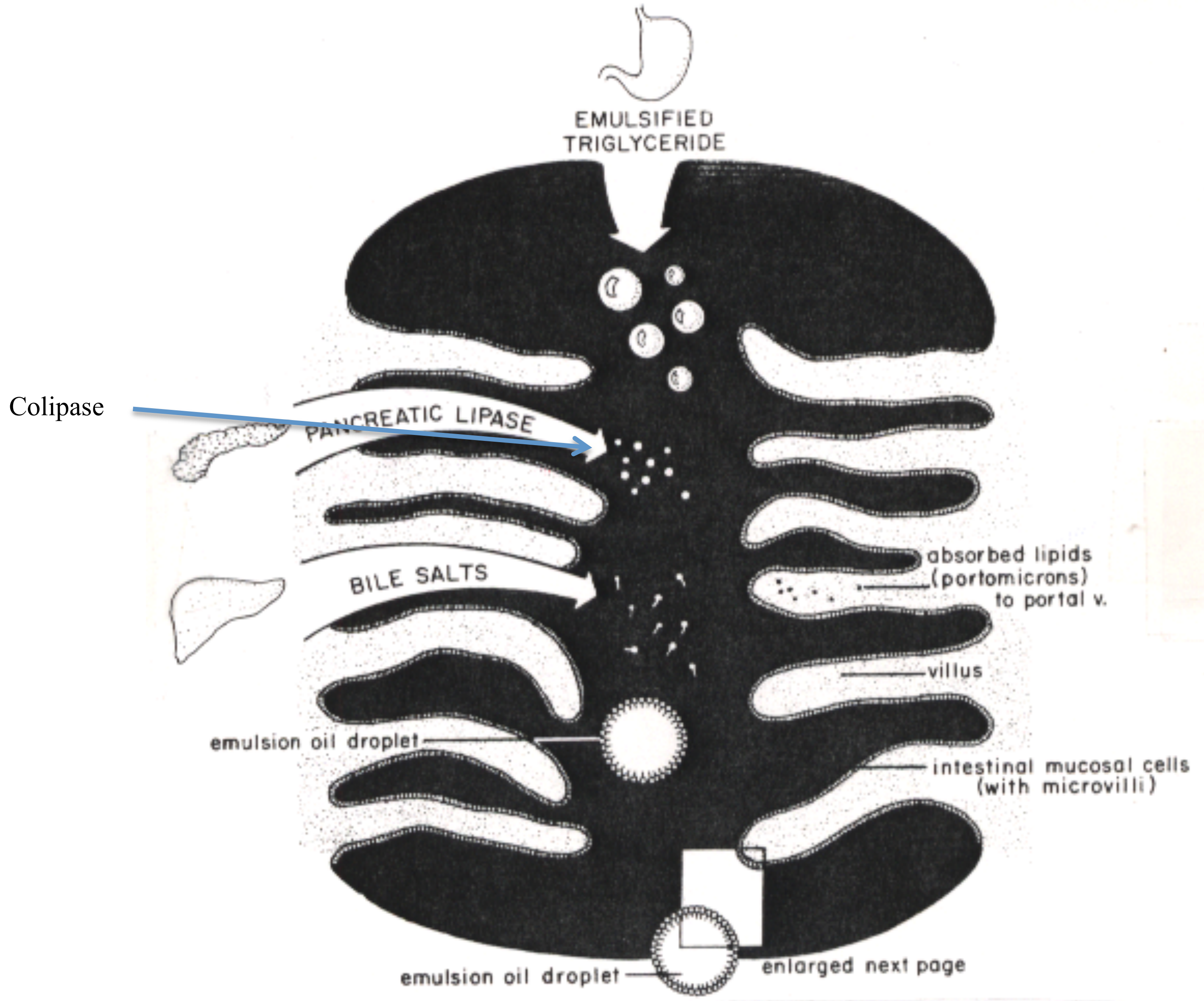
IV. Digestion of fats in the small intestine

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

1. Gall bladder contraction.

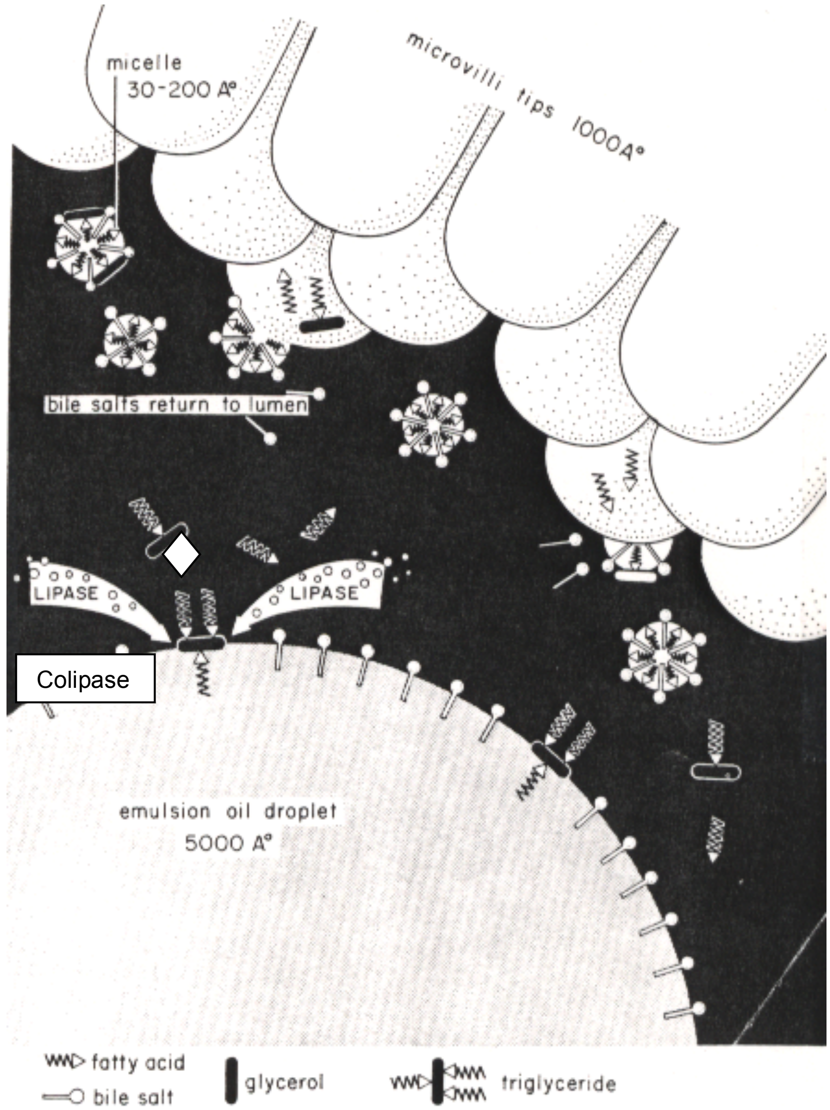
    a. The gall bladder contains 40 to 70 mL.

    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.*

Fatty acid + ATP + CoA-SH → Fatty acyl-CoA (FACoA) + AMP + PP_i

(→ $2P_i$; This pulls the reaction to the right.)

2-MAG + FACoA → 1,2-DAG

1,2-DAG + FACoA → TAG

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

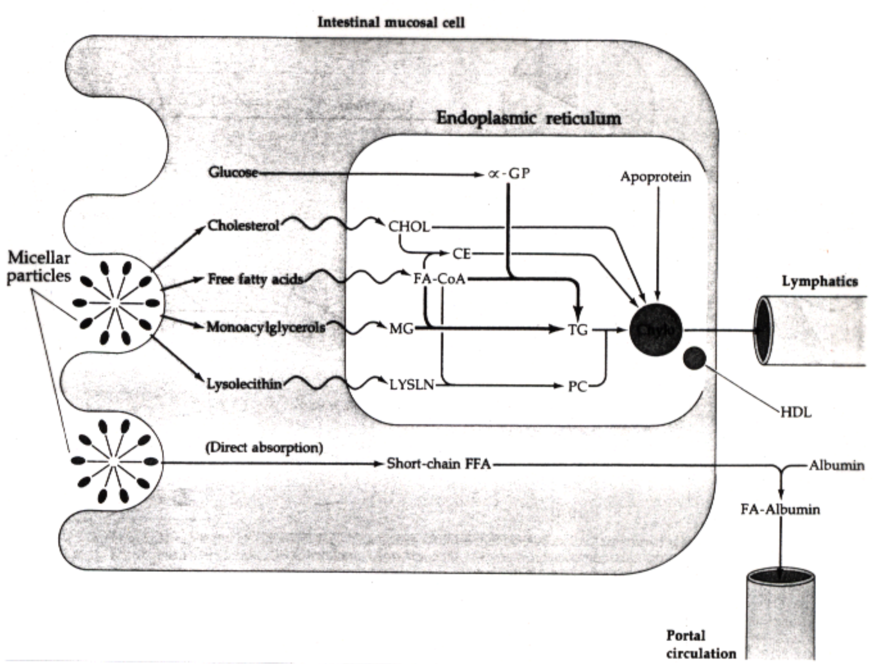
glucose → glycerol-3-phosphate (G-3-P)

G-3-P + FACoA → 1-lyso-phosphatidic acid

1-lyso-phosphatidic acid +FACoA → 1,2-phosphatidic acid

1,2-phosphatidic acid → 1,2-diacylglycerol + P_i

1,2-DAG + FACoA → TAG



B. Phospholipids

1. Phosphatidylcholine (lecithin)

lyso-phosphatidylcholine + FACoA → phosphatidylcholine

2. Others – Phosphatidylethanolamine, phosphatidyl serine

C. Cholesterol esters: **Cholesterol + FACoA → Cholesterol ester**

VII. Chylomicrons

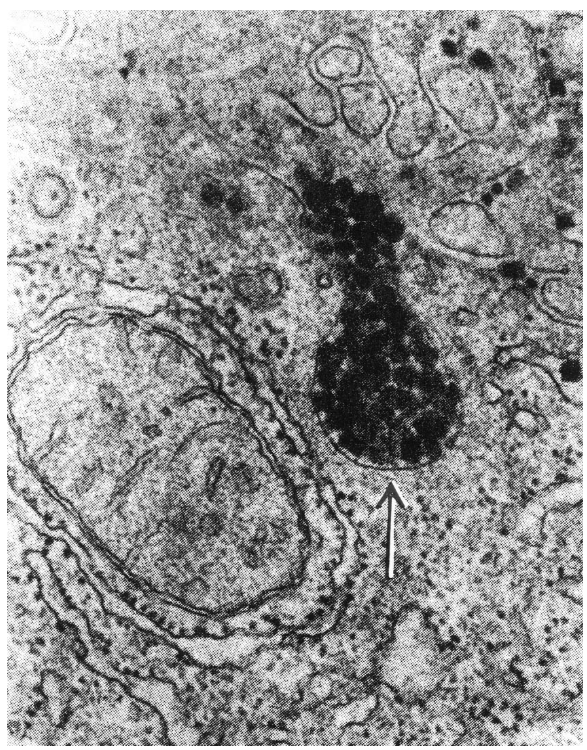
A. Synthesis

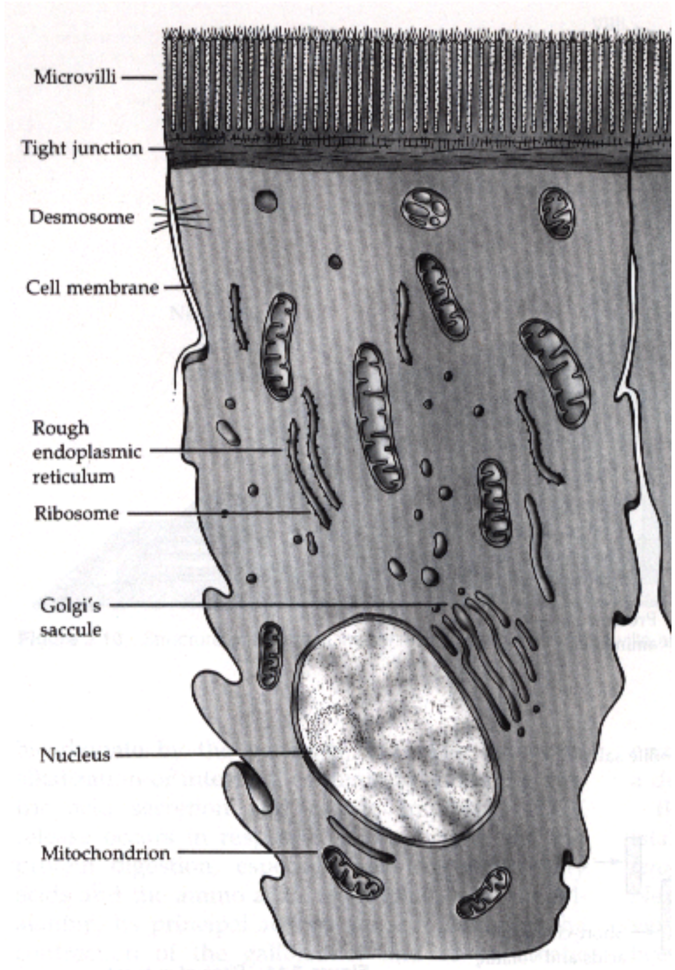
1. Lipid droplets form within the endoplasmic reticulum and Golgi apparatus.
2. Lipid droplets contain TAG, phospholipid, cholesterol, cholesterol ester, and apolipoprotein (with carbohydrate) complexes.
    a. Apolipoproteins and phospholipids are formed in the rough endoplasmic reticulum.
    b. TAG are formed in the smooth endoplasmic reticulum and are transferred to $ApoB_{48}$ 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 subclavean 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

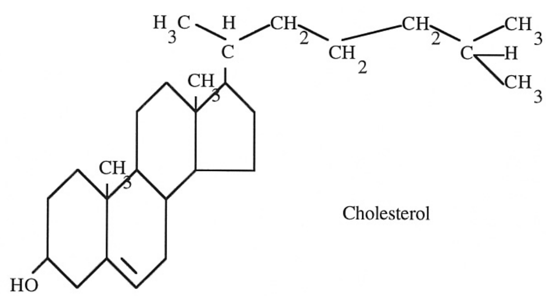
1. Cholesterol esters are hydrolyzed by pancreatic cholesterol esterases.

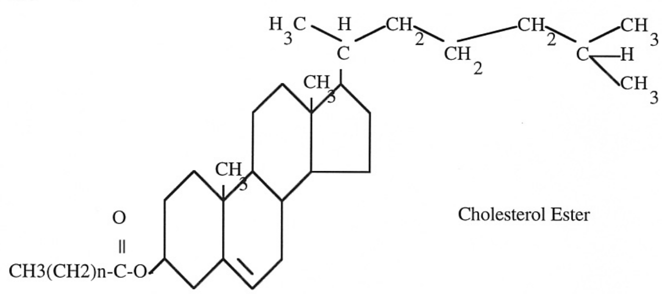
2. Free cholesterol is incorporated into mixed micelles. (In the absence of bile acids cholesterol absorption is negligible.)

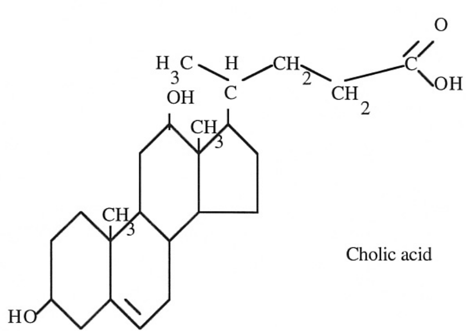
3. Free cholesterol is absorbed into the intestinal mucosal cells and re-esterified to form cholesterol esters.

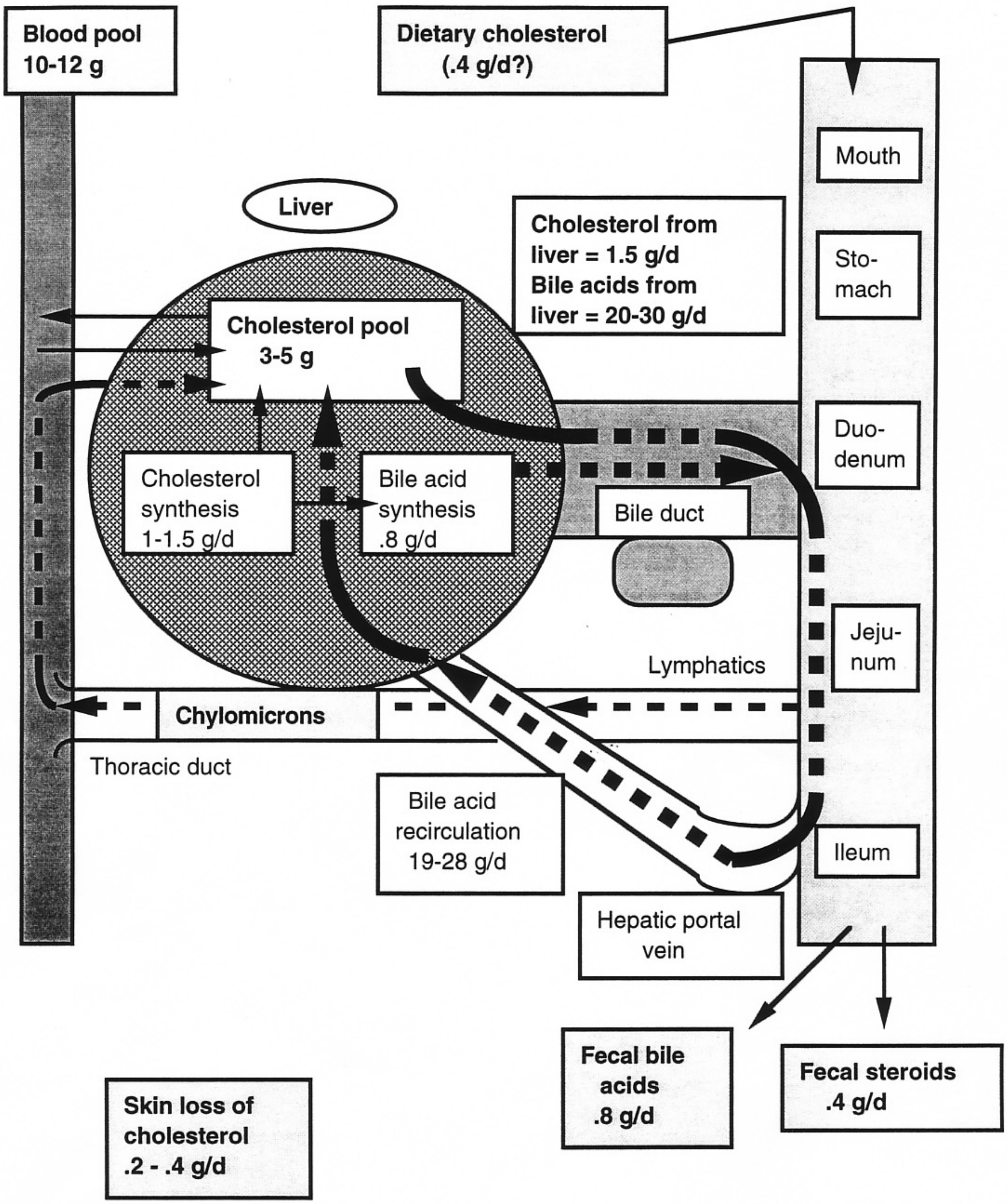
C. Sources of loss of cholesterol from the dietary tract

1. Bile salts
   a. 0.8 g/d bile salts are lost in the feces.
   b. The remainder (98 - 99%) is taken up in the ileum (enterohepatic circulation).
2. Cholesterol: cholesterol is poorly absorbed.
   a. Approximately 0.4 g/d lost in the feces
   b. Only 30 to 60% dietary plus biliary cholesterol absorbed.
   c. Increased cholesterol intake results in a **greater amount** of cholesterol absorbed, but a **lesser percentage** absorbed.
3. Plant sterols
   a. 200 to 300 mg/d are ingested.
   b. Plant sterols are absorbed only in trace amounts.
   c. 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.


Cholesterol


Cholesterol Ester


Cholic acid


Blood pool
10-12 g
Dietary cholesterol
(.4 g/d?)
Mouth
Liver
Cholesterol from
liver = 1.5 g/d
Bile acids from
liver = 20-30 g/d
Sto-
mach
Cholesterol pool
3-5 g
Duo-
denum
Cholesterol
synthesis
1-1.5 g/d
Bile acid
synthesis
.8 g/d
Bile duct
Jeju-
num
Lymphatics
Chylomicrons
Thoracic duct
Bile acid
recirculation
19-28 g/d
Ileum
Hepatic portal
vein
Fecal bile
acids
.8 g/d
Fecal steroids
.4 g/d
Skin loss of
cholesterol
.2 - .4 g/d