Nutrition

for Sport and Exercise, Third Edition

Marie Dunford
J. Andrew Doyle

4 Carbohydrates

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Learning Objectives

- Classify carbohydrates according to their chemical composition
- Describe the digestion and absorption of carbohydrates
- Describe how muscle glycogen and blood glucose are used to fuel exercise
- Detail and explain carbohydrate recommendations for athletes, including specific guidelines for intake before, during, and after exercise
- Determine the daily carbohydrate needs of an athlete, and select carbohydrate-containing foods to meet the recommended intake

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The Carbohydrate Equation

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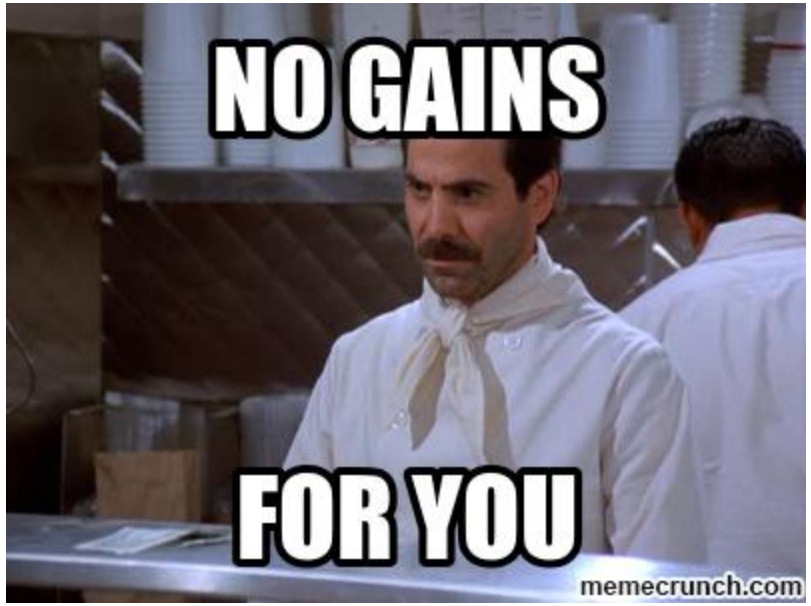

No Carbs (Glycogen) + High Intensity Exercise = No Gainz

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Type of Diet	Muscle Glycogen	Time to Exhaustion
Low CHO (<5% CHO)	38 mmol/kg	60 minutes
Mixed Diet (50% CHO)	106 mmol/kg	115 minutes
High CHO (>83% CHO)	204 mmol/kg	170 minutes

Carbohydrates in Food

- Carbohydrates are found in a wide variety of foods including breads, cereals, pastas, beans, fruits, vegetables, milk, and nuts

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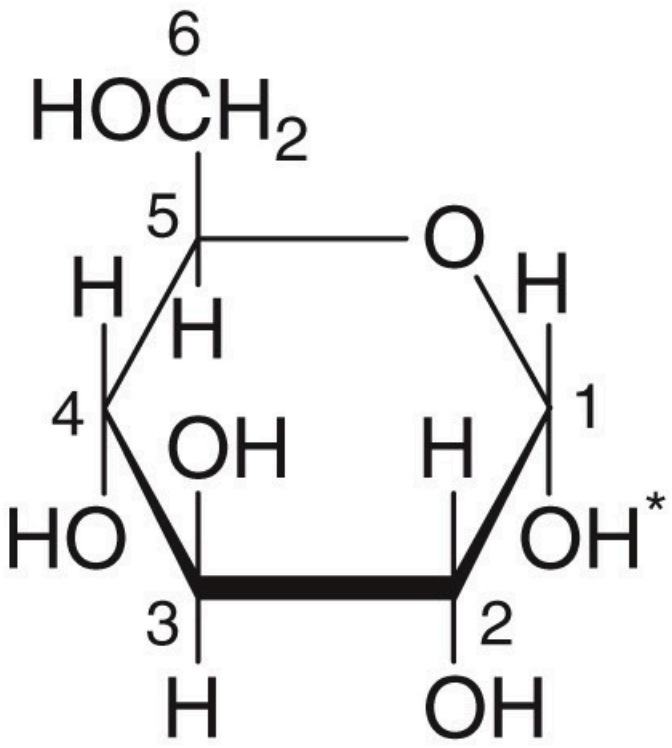
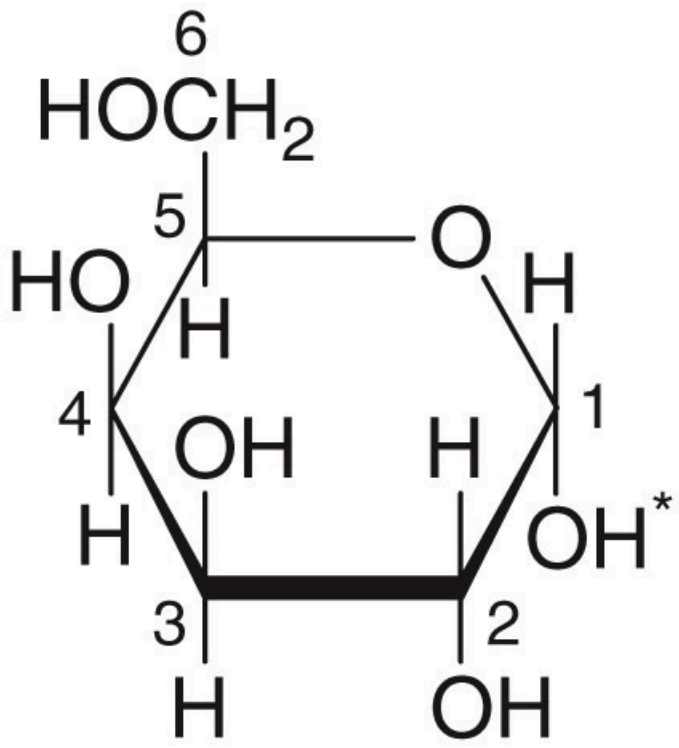
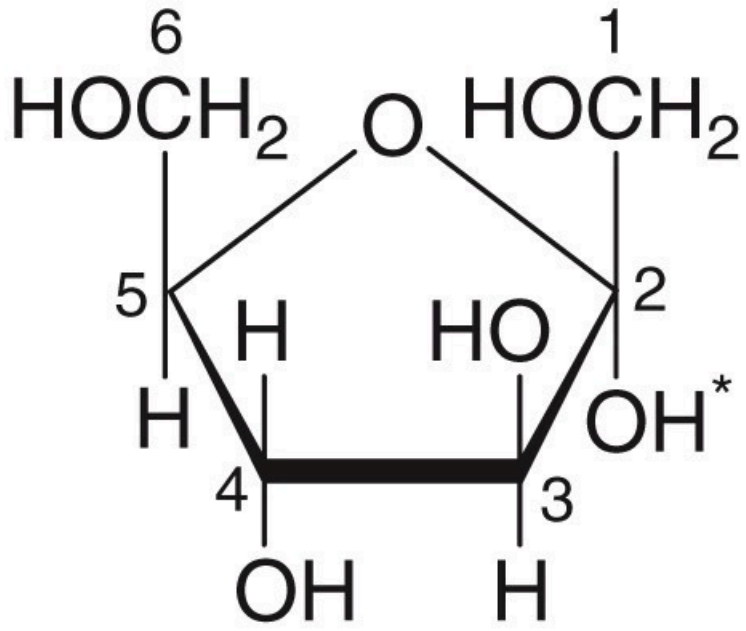
Carbohydrates in Food - Monosaccharides



D-glucose



D-galactose



D-fructose

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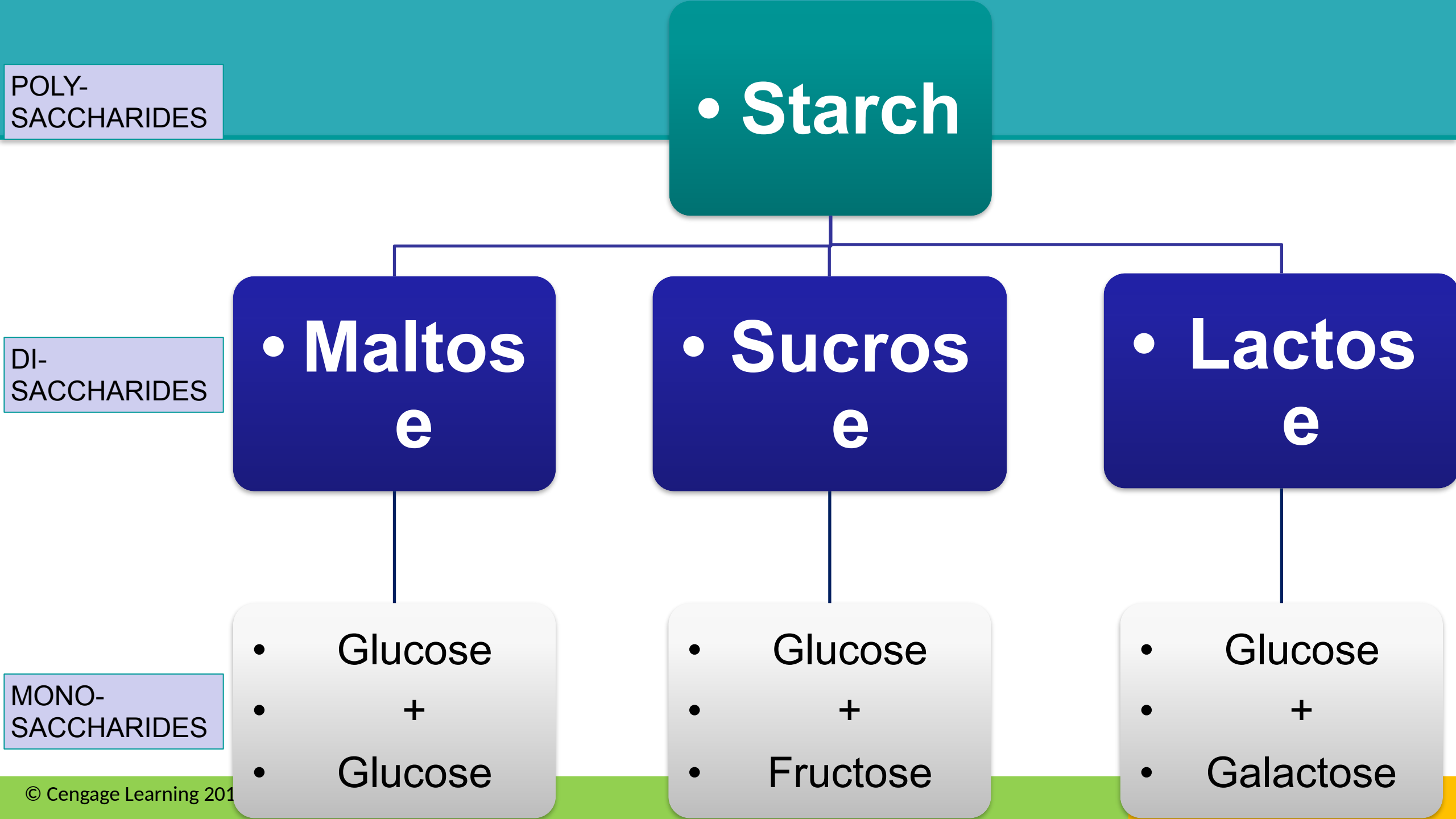

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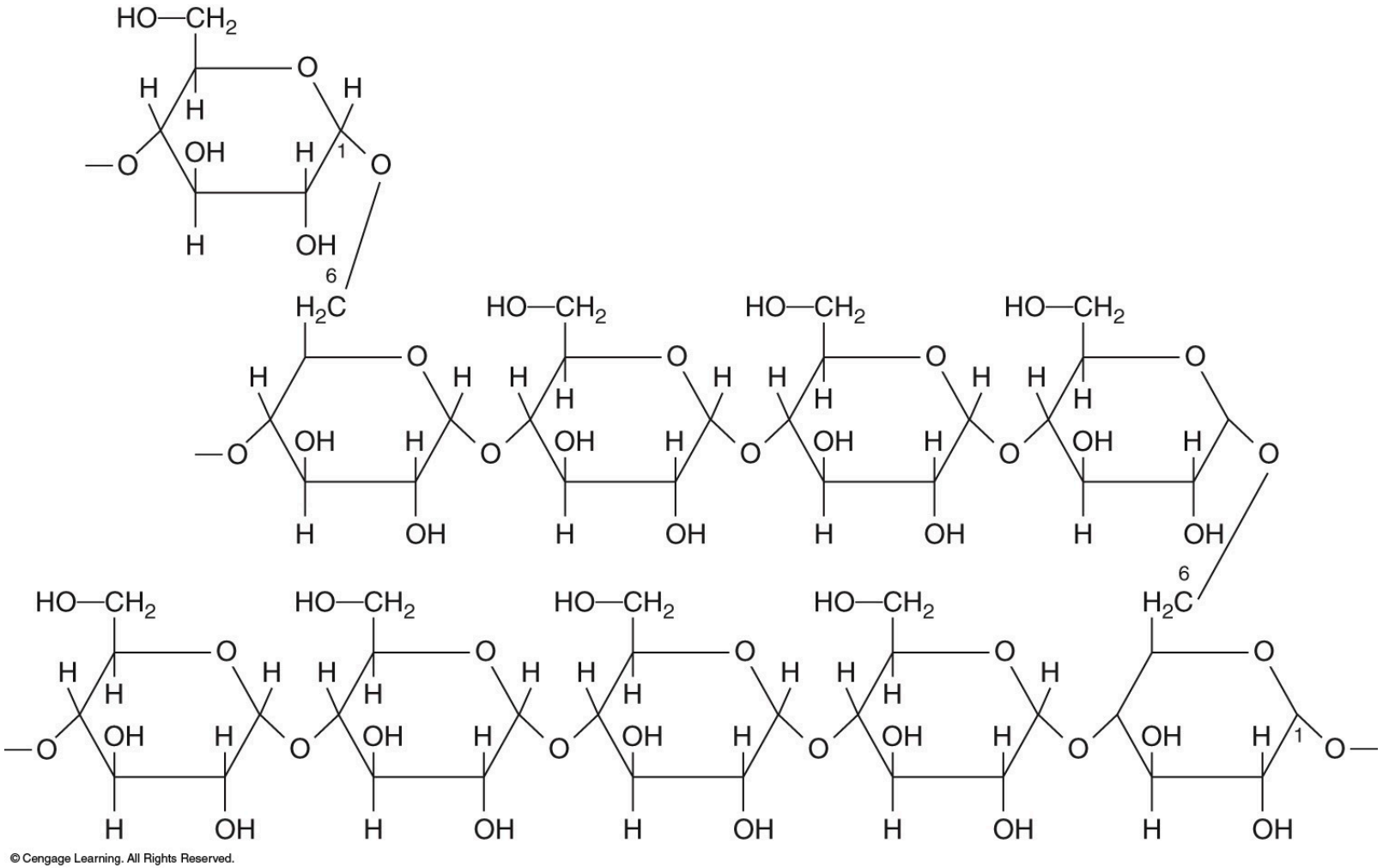
Carbohydrates in Food - Glycogen



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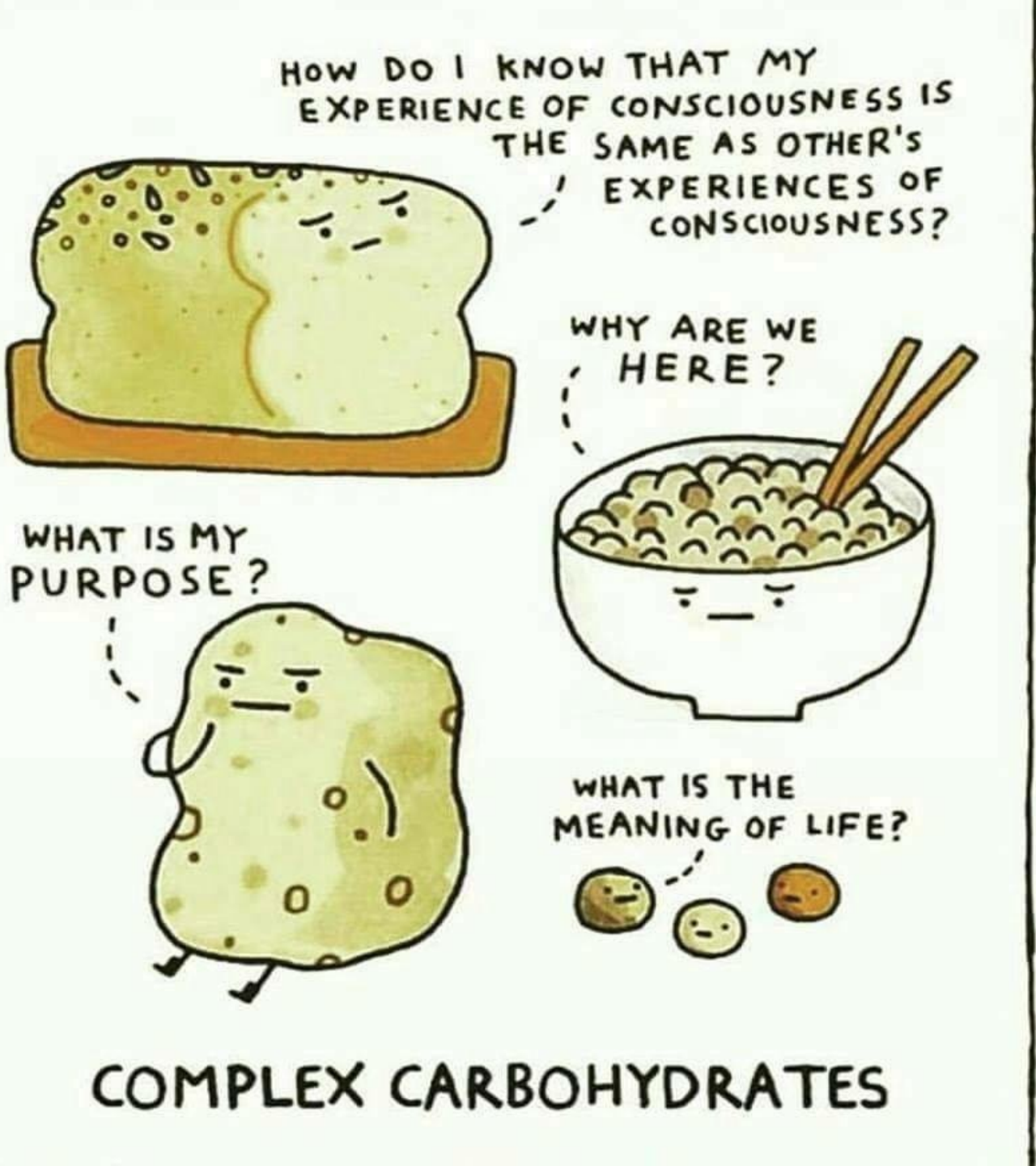
Classifying Food Carbohydrat

- There is no single way to classify carbohydrates
  - Sugars and starches
  - **Simple and complex**
  - Minimally processed ("qualit vs. highly processed
  - "Good" vs. "Bad"



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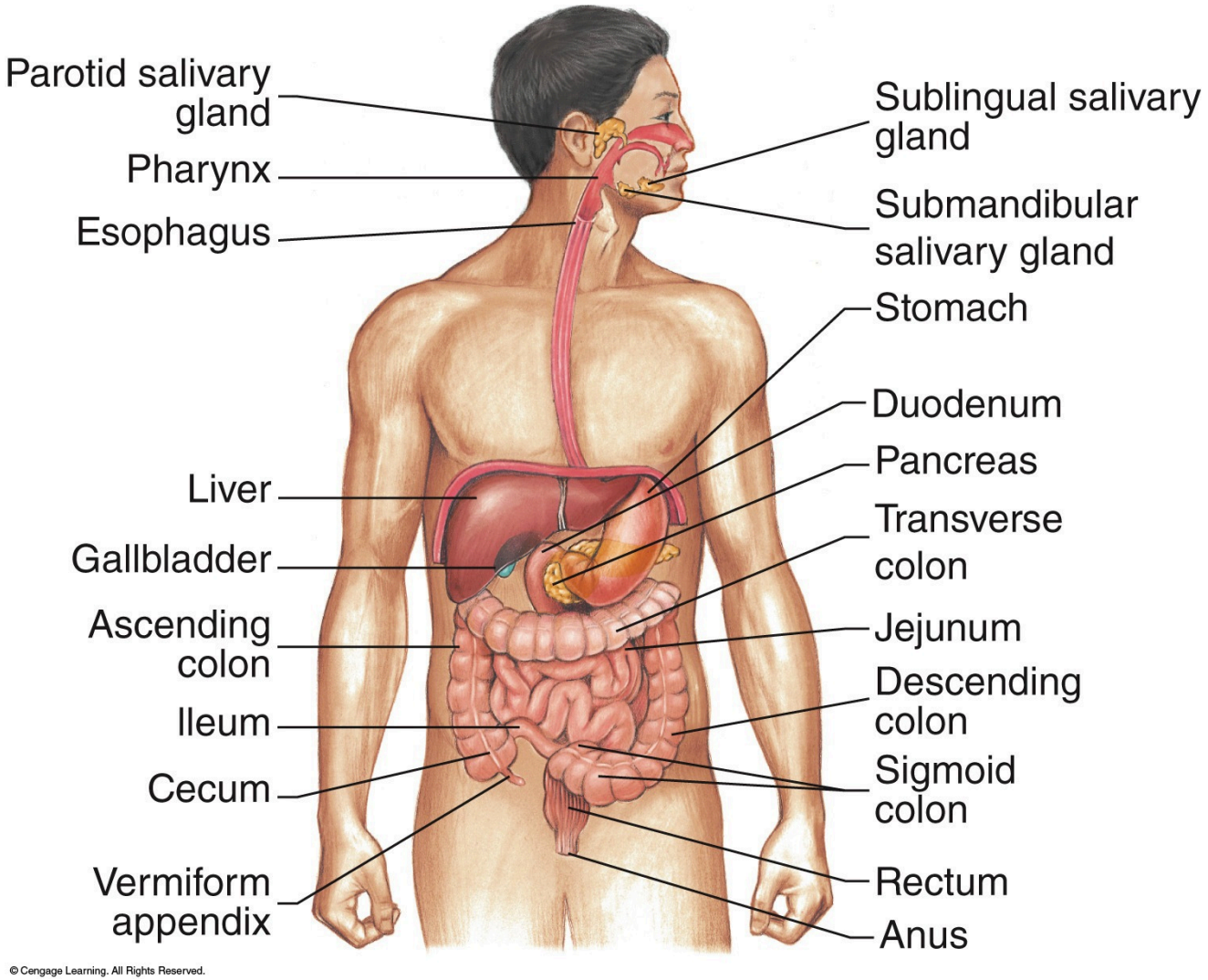
4.2 Digestion, Absorption, and Transportation of Carbohydrates



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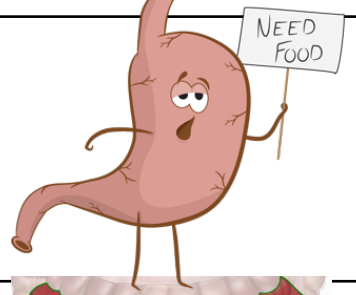
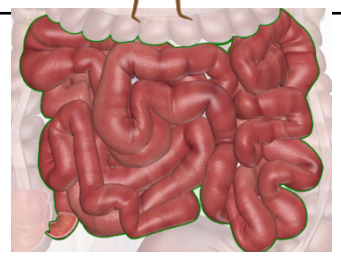
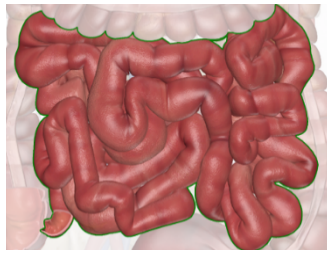
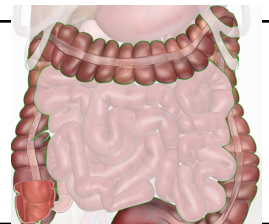
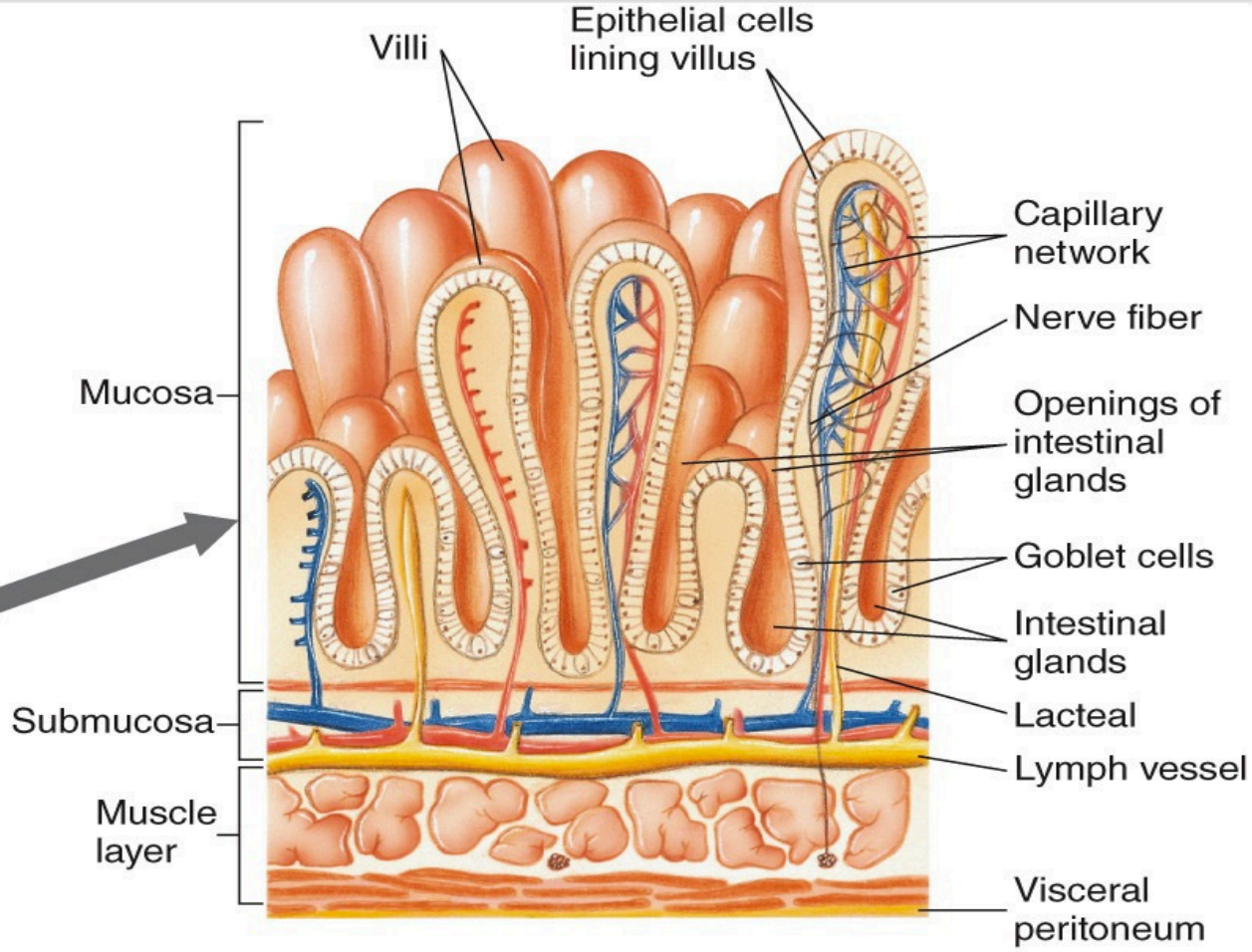
Carbohydrate Digestion

	• Amylase (enzyme) – breakdown starch into smaller units
	• Amylase activity inhibited • Carb digestion slows
	• Duodenum (first part of Small Intestine) – pancreatic enzymes increases carb breakdown
	• Brush Boarder of Small Intestine – disaccharides broken down into monosaccharides for digestion
	• Fermentation of some fiber, the rest is excreted

The Structure of the Small Intestine

Steve Gschmeissner/Science Source

Light micrograph of a section through the entire width of the small intestine. Magnification: x60



Enlarged view of a small portion of the intestinal wall. Some of the villi have been opened to show the blood and lymph vessels within.

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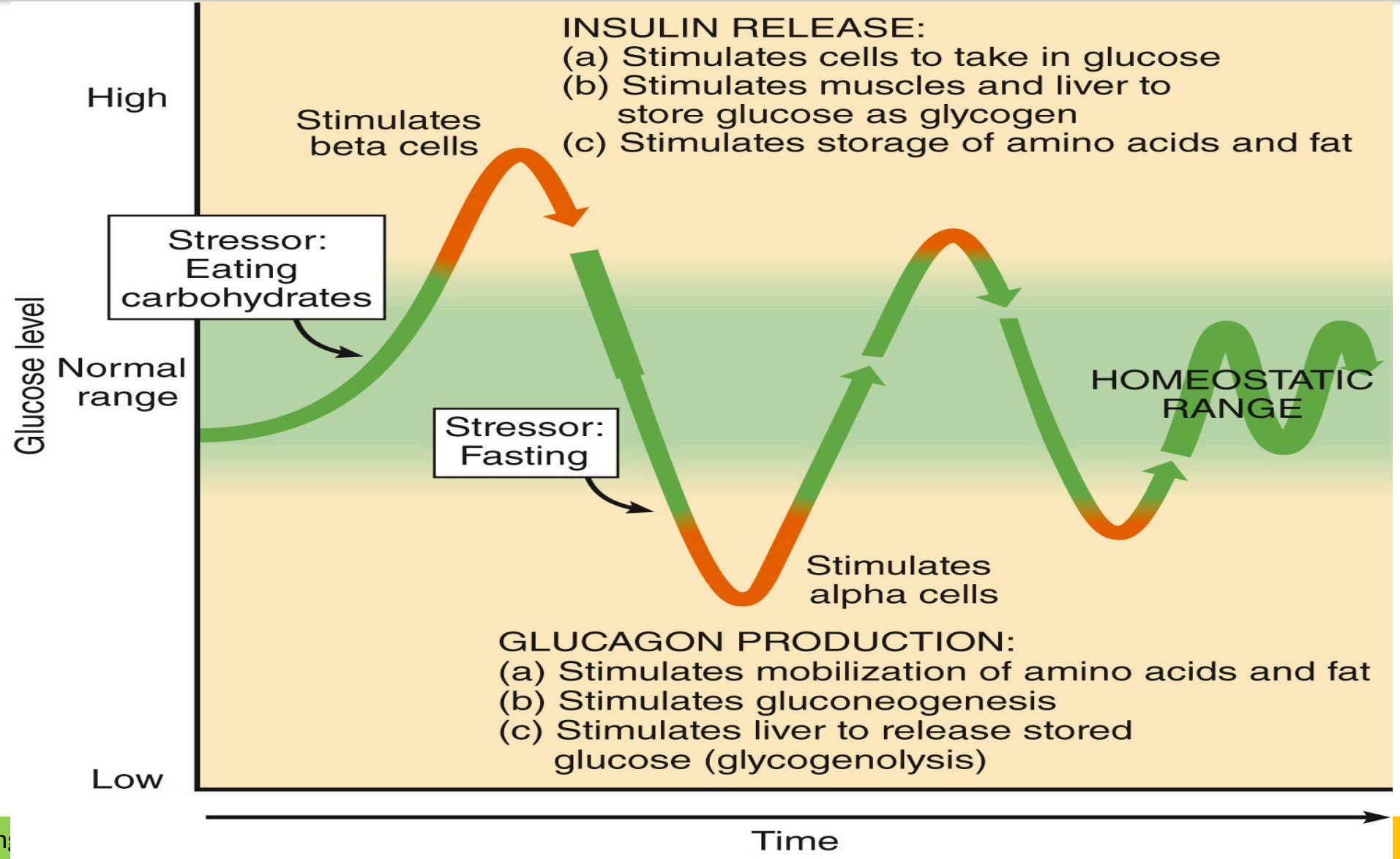
4.3 Metabolism of Glucose in the Body



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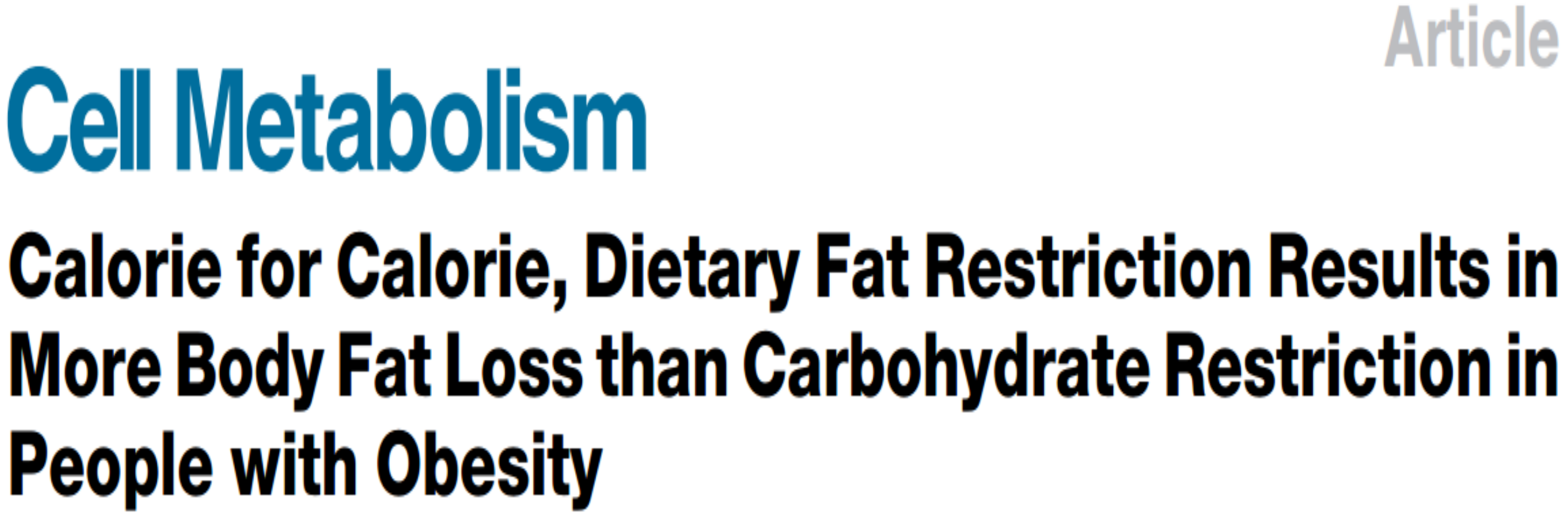
Do Carbs Make You Fat?

- Nope!



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Metabolism of Glucose in the Body

- These foods all contain carbohydrate, but each has a different effect on blood glucose (known as glycemic response)

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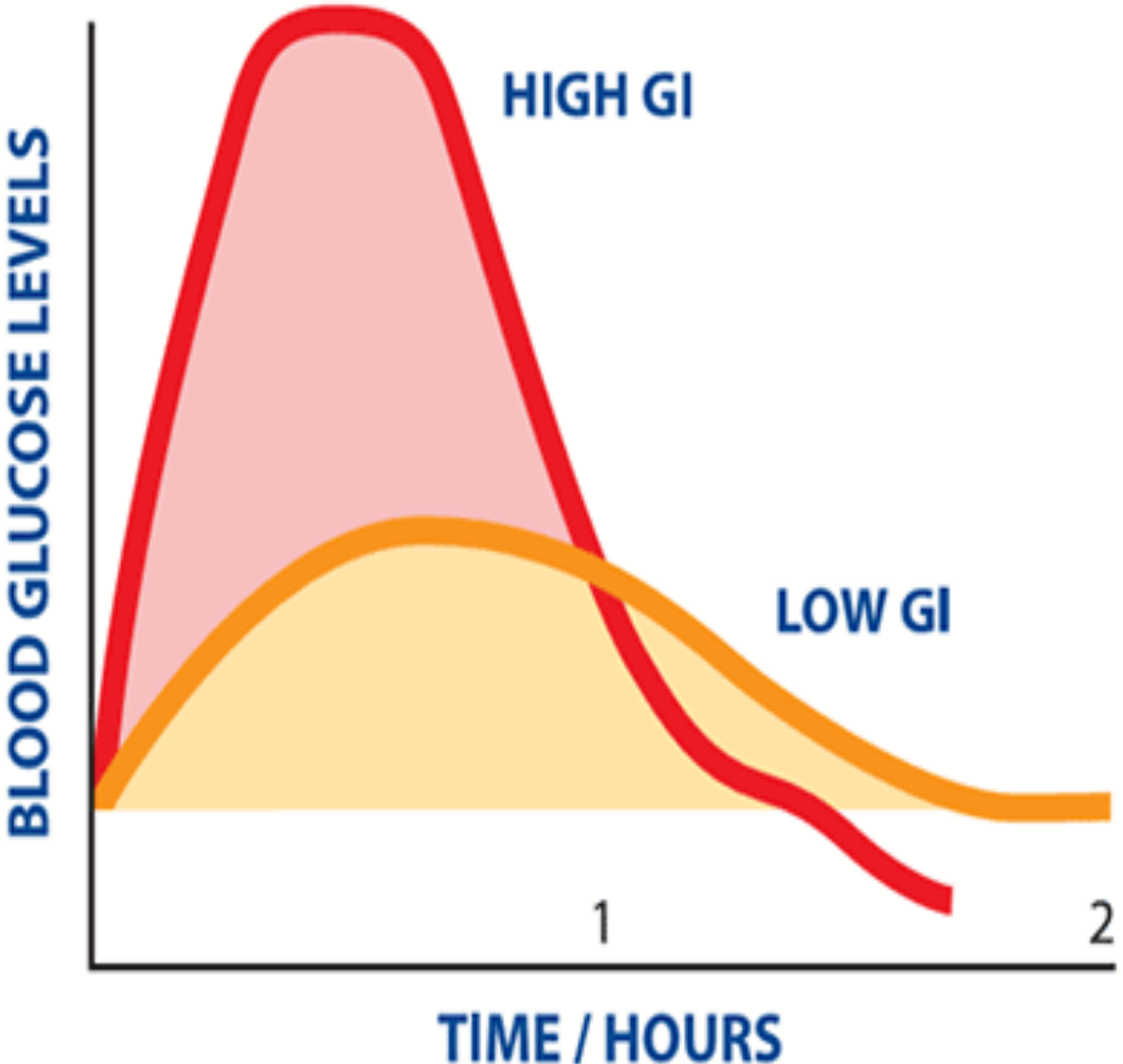
Glycemic Index

- The glycemic index (GI) is a ranking of carbohydrates on a scale from 0 to 100 according to the extent to which they raise blood sugar levels after eating
  - High GI is >70
  - Moderate GI is 56-70
  - Low GI is ≤ 55



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Glycemic Load

$$\text{Glycemic Load} = \frac{\text{GI} * \text{Amount of CHO (g) in one serving}}{100}$$

- Takes GI index into account but also gives a fuller picture
- Low GL 1-10 | Medium GL 11-19 | High GL ≥20
- Foods with a low GL almost always have a low GI

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TABLE 6.1

Glycemic Index (GI) and Glycemic Load (GL)

Food	GI	Serving size (g)	Available carbohydrate (g)	GL (per serving)
HIGH GI (>70)				
Boiled potato	101	150	17	17
Glucose	99	10	10	10
Baked potato	85	150	30	26
Lucozade, original	95	250 (ml)	42	40
Pancakes, buckwheat	102	77	22	22
Pretzels	83	30	20	16
Scones	92	25	9	7
Gatorade	78	250 (ml)	15	12
Isostar	70	250 (ml)	18	13
Bagel	72	70	35	25
Baguette, white, plain	95	70	37	27
Cheerios cereal	74	30	20	15
Corn flakes	81	30	26	21
Shredded wheat	75	30	20	15
K-time strawberry crunch bar	77	30	25	19
Puffed rice cakes	78	25	21	17
Watermelon	72	120	6	4
Popcorn	72	20	11	8
Stir fried vegetables	73	360	75	55

TABLE 6.1

Glycemic Index (GI) and Glycemic Load (GL)

Food	GI	Serving size (g)	Available carbohydrate (g)	GL (per serving)
MODERATE GI (56–70)				
Doughnut	67	47	23	17
Croissant	67	57	26	17
Blueberry muffin	60	57	29	17
Coca-Cola	58	250 (ml)	26	16
French baguette with butter and strawberry jam	62	70	41	26
Porridge	58	250 (ml)	22	13
Rice, white, boiled	64	150	36	23
Long-grain rice, boiled	56	150	41	23
Digestives (cookies)	59	25	16	10
Oreo cookies	64	40	32	20
Ice cream, regular	61	50	13	8
Fruit cocktail, canned	55	120	16	9
Mars bar	65	60	40	26
Snickers bar	55	60	35	19
Power bar, chocolate	56	65	42	24
Ironman PR bar	39	65	26	10

TABLE 6.1 (CONTINUED)

Food	GI	Serving size (g)	Available carbohydrate (g)	GL (per serving)
LOW GI (<55)				
Honey	55	25	18	10
Potato crisps/chips	54	50	21	11
Sweet corn	54	80	17	9
Pizza, Super Supreme (Pizza Hut)	36	100	24	9
Wheat bread	53	30	20	11
Carrots	47	80	6	3
Orange juice	50	250 (ml)	26	13
Apple juice	40	250 (ml)	29	12
Rye bread	41	30	12	5
All-Bran cereal	42	30	23	9
Baked beans	48	150	15	7
Kidney beans	28	150	25	7
Lentils	30	150	17	5
Smoothie, raspberry	33	250 (ml)	41	14

TABLE 6.1 (CONTINUED)

Food	GI	Serving size (g)	Available carbohydrate (g)	GL (per serving)
LOW GI (<55)				
Muesli	49	30	20	10
Prince Fourre chocolate cookies	52	45	30	16
Ice cream, low-fat, vanilla	50	50	6	3
Spaghetti, boiled	38	180	48	18
Chocolate milk, plain	43	50	28	12
Skim milk	32	250 (ml)	13	4
Milk, full-fat	27	250 (ml)	12	3
Yogurt	36	200	9	3
Low-fat yogurt	24	200	14	3
Apple	38	120	15	6
Banana	52	120	24	12
Orange	42	120	11	5
Grapes	46	120	18	8
Peach	42	120	11	5
Peanuts	14	50	6	1
Fructose	19	10	10	2

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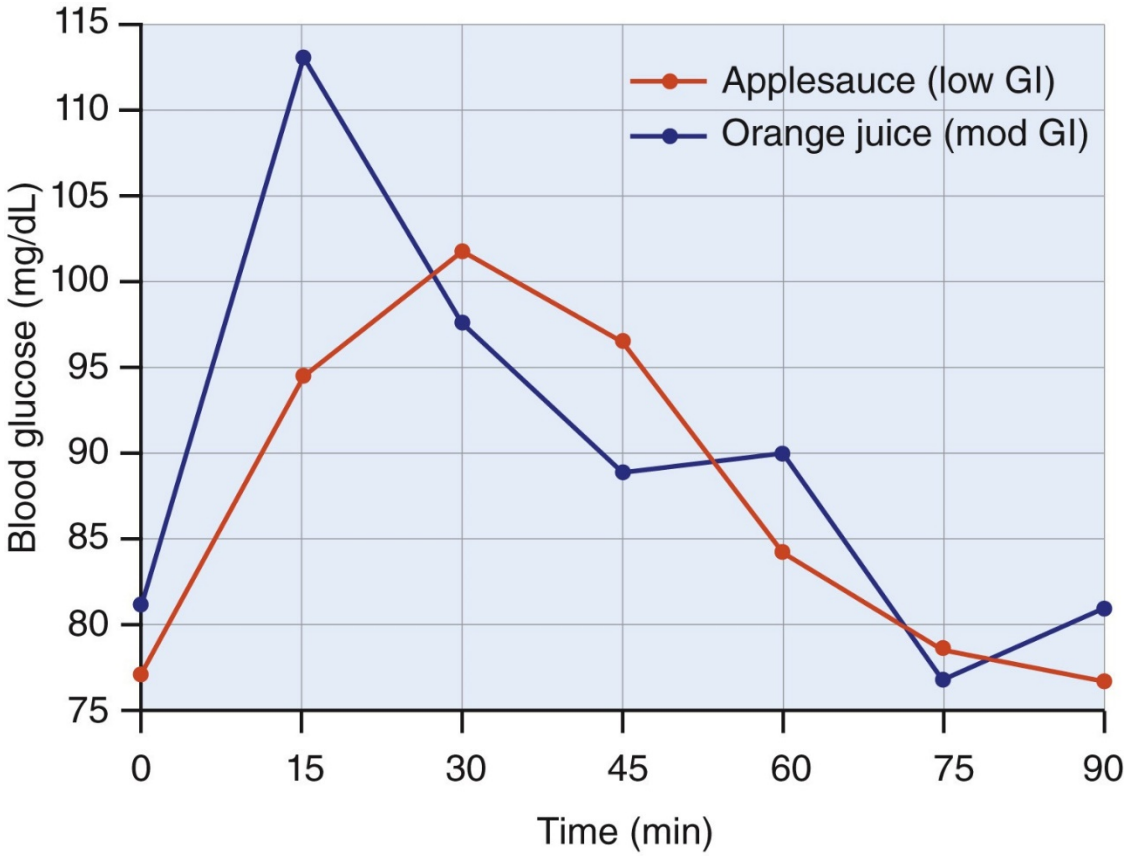
Metabolism of Glucose in the Body



mg/dL = milligrams per deciliter
mod = moderate
min = minutes

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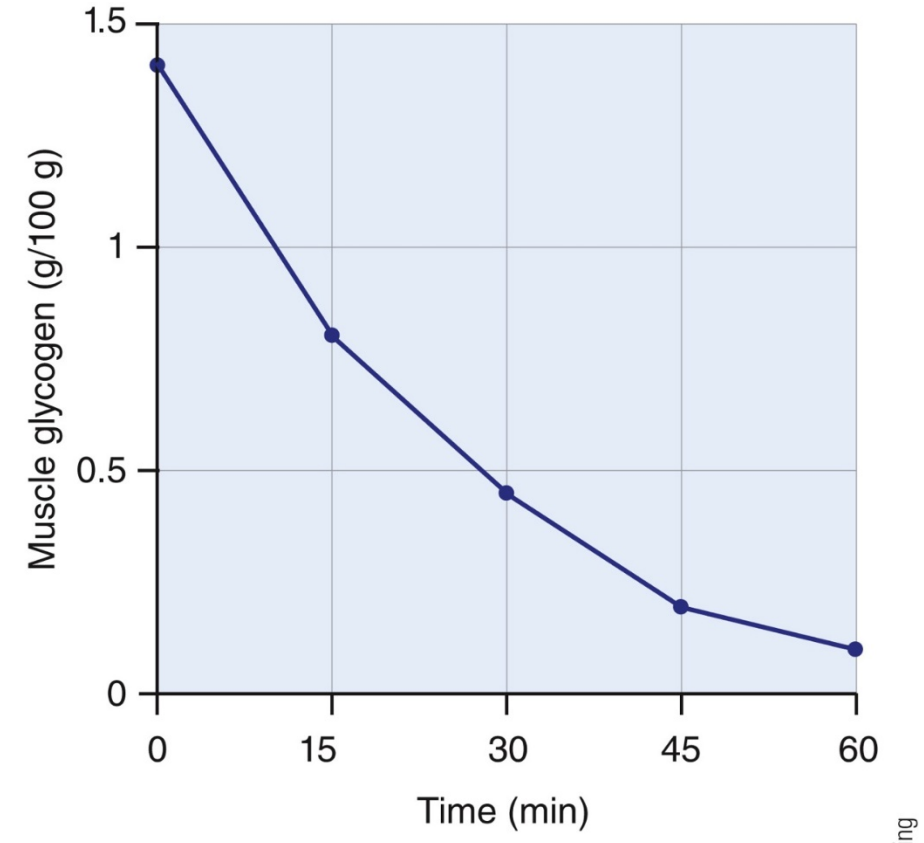
4.4 Carbohydrates as a Source of Energy for Exercise



Redrawn from: Bergström, J., and Hultman, E. (1967). A study of the glycogen metabolism during exercise in man. *Scandinavian Journal of Clinical Laboratory Investigation, 19*(3), 218–228.

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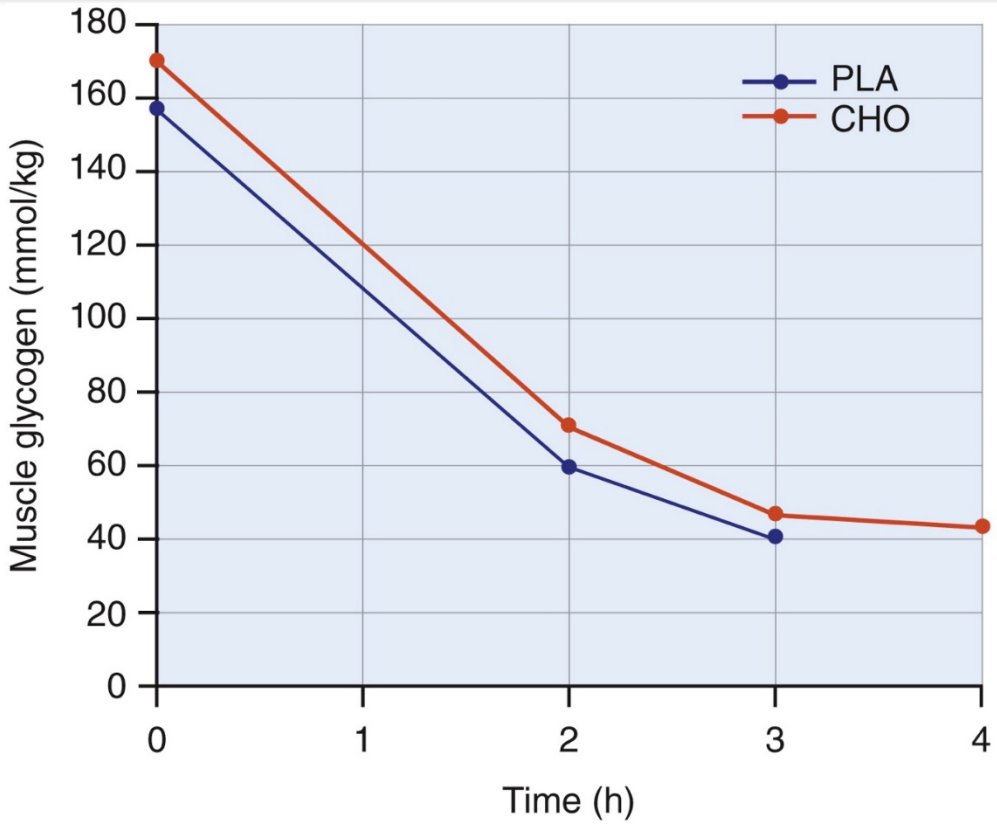
Exercising Muscle Takes Up and Metabolizes Blood Glucose



mmol/kg = millimoles per kilogram
PLA = placebo
CHO = carbohydrate
h = hour

Redrawn from: Coyle, E.F., Coggan, A.R., Hemmert, M.K., & Ivy, J.L. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology, 61*(1), 165–172.

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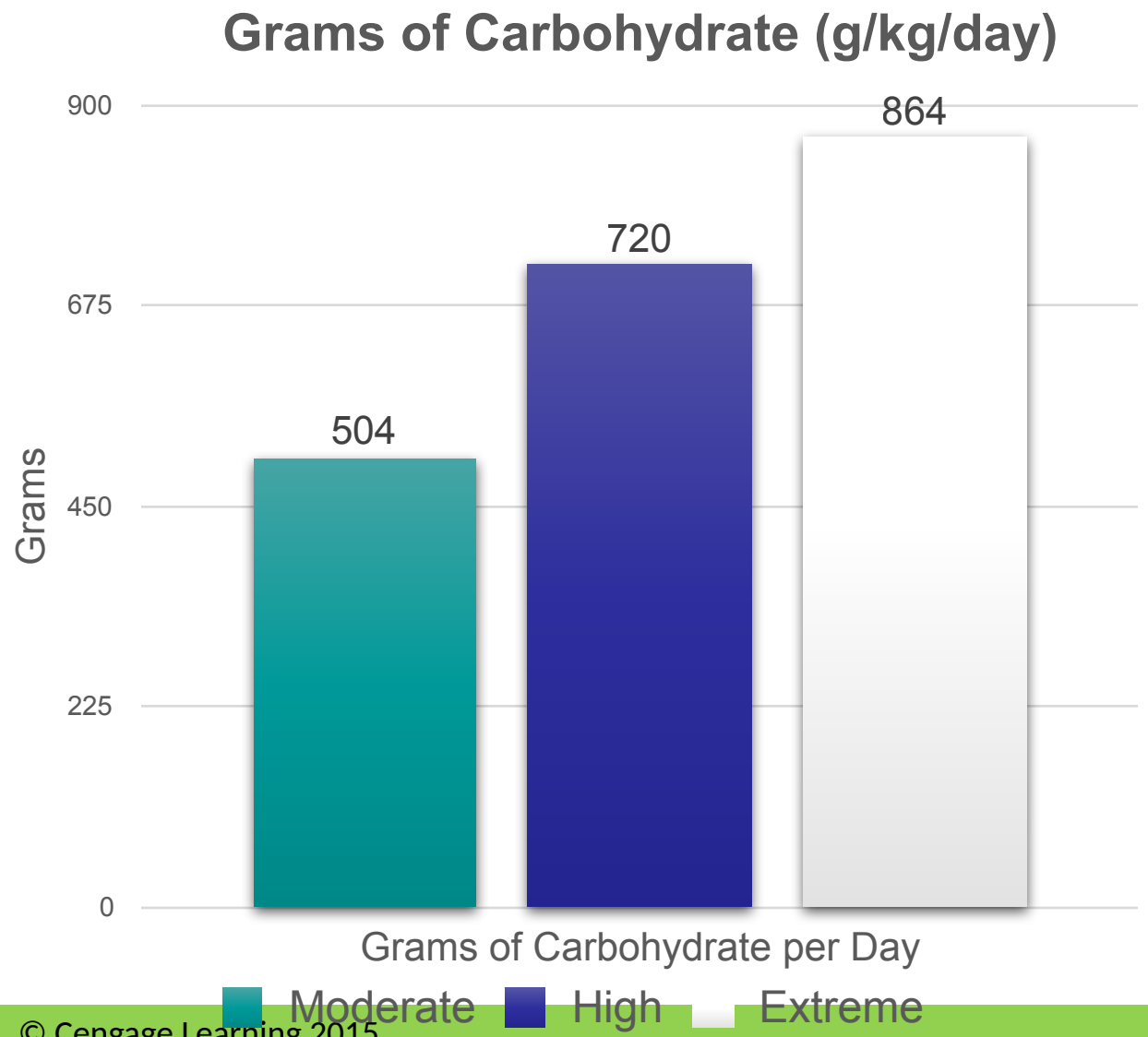
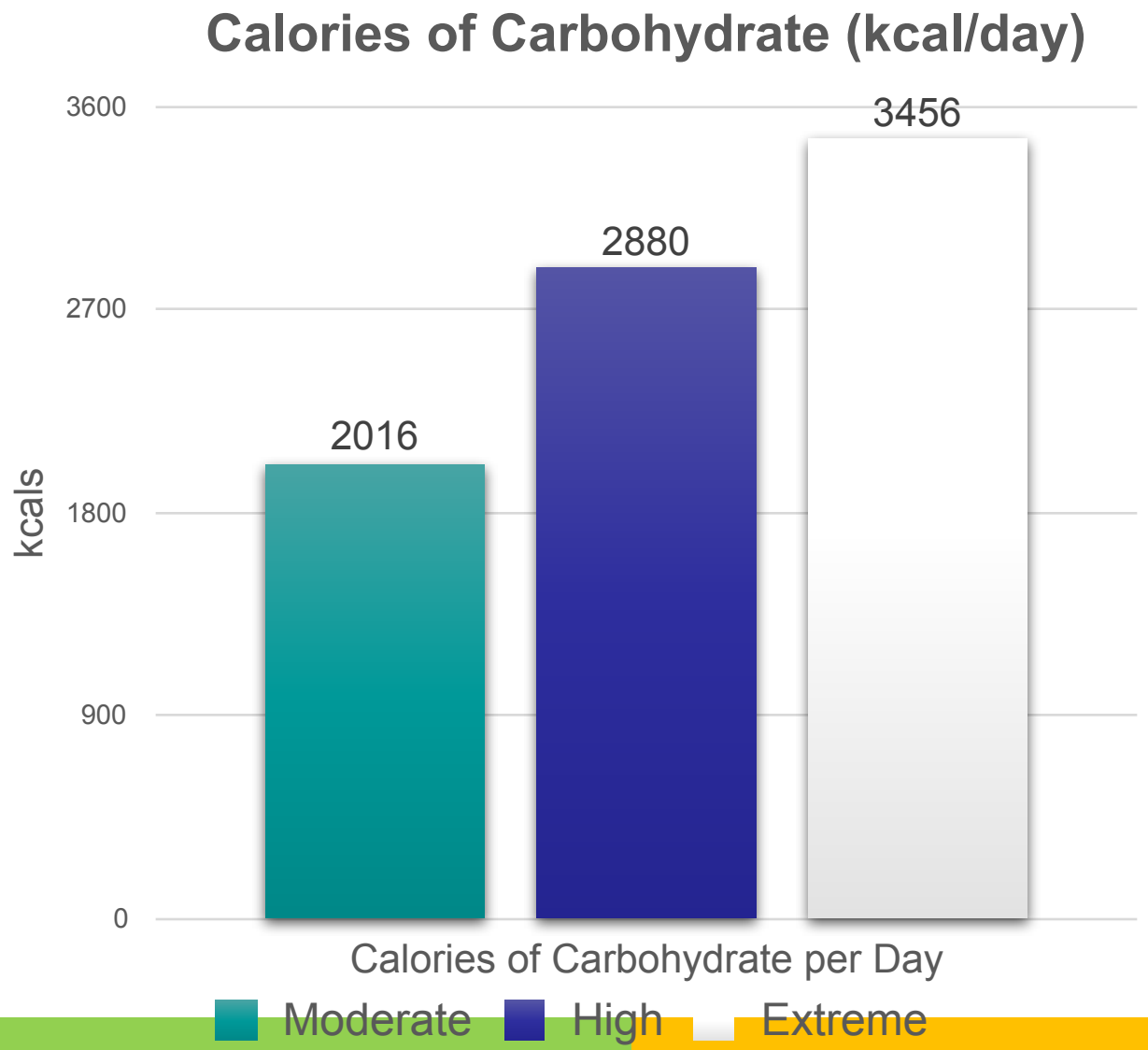
4.5 Carbohydrate Recommendations for Athletes

	International Olympic Committee (IOC) Consensus Statement on Sports Nutrition 2012	ADA/ACSM/DOC Position Statement: Nutrition & Athletic Performance 2009
Moderate Intensity	5-7 g/kg/day	**6-7 g/kg/day**
High Intensity	7-10 g/kg/day	**8-9 g/kg/day**
Extreme Intensity	10-12+ g/kg/day	**10+ g/kg/day**

Carbohydrate Needs for 160 Lbs. Athletes





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Athlete Vs. Average Joe

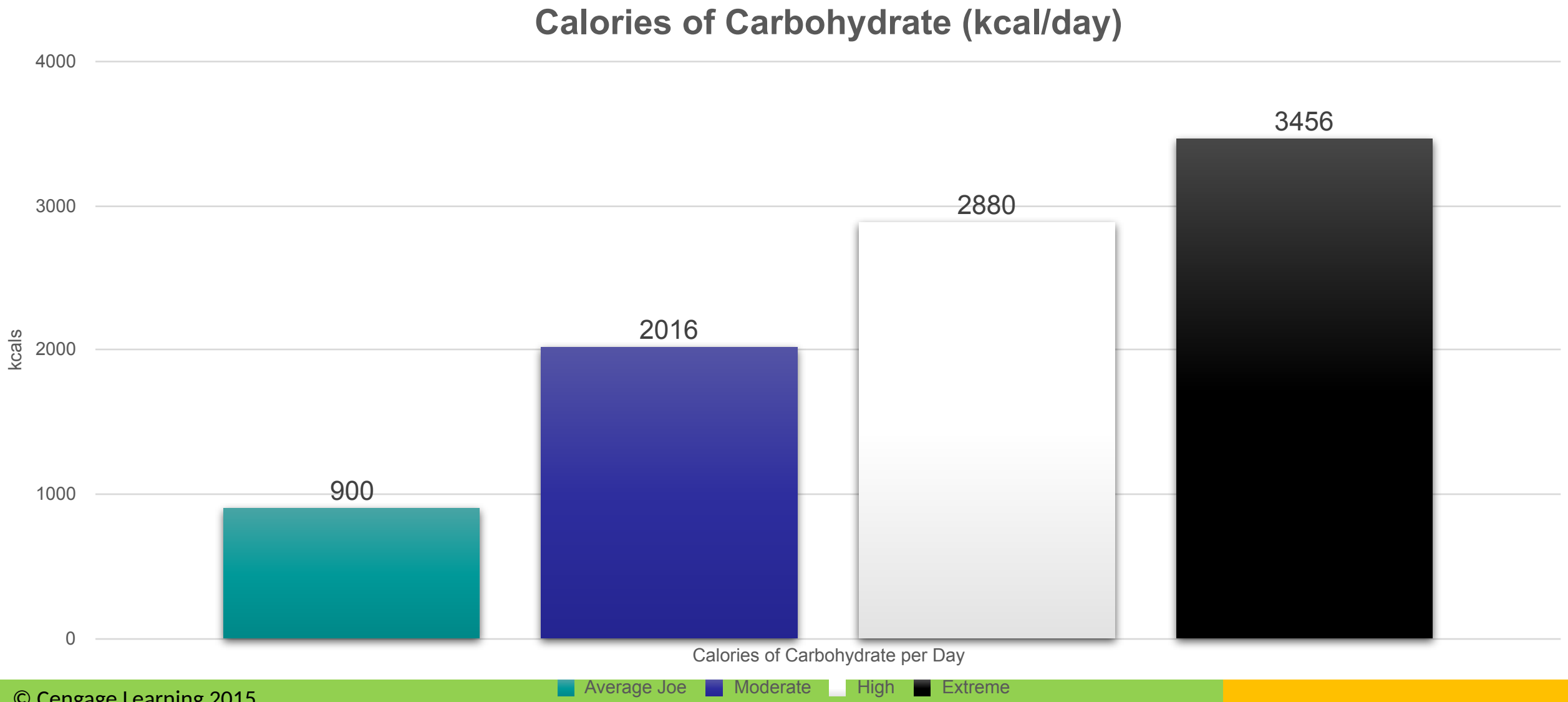

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Table 4.7 Carbohydrate Intake during Exercise to Enhance Performance

Exercise intensity and duration	Sport or event	Recommended carbohydrate intake to enhance performance*
High-intensity exercise less than 45 minutes	Running (sprints up to 10 km); cycling (track cycling, short criteriums); swimming (sprints up to 1500 m); crew (rowing)	None
High-intensity exercise (continuous or intermittent) approximately 45–60 minutes	Team sports, such as basketball, lacrosse, water polo, or ice hockey; cycling time trials	0–30 g/h
High-intensity exercise (intermittent) approximately 90 minutes	Team sports, such as soccer; skilled recreational tennis players; team or individual handball, racquetball, or squash	30–50 g/h
Moderate to vigorous exercise more than 2 hours	Backpacking, hiking; recreational cycling	30–60 g/h**
High-intensity exercise more than 2 hours	Marathon running; sprint and Olympic distance triathlon; 50 km ski racing; professional tennis match	50–70 g/h**
Ultraendurance competitions lasting many hours or repeated over days	Ironman length triathlons; cycling stage races, adventure racing	60–90 g/h**

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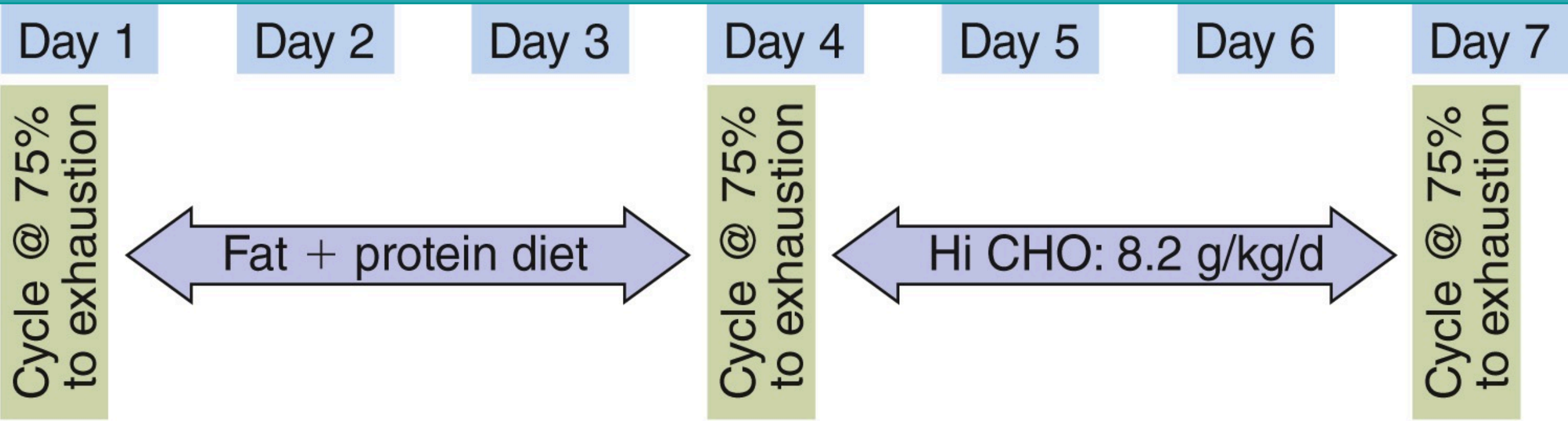
g/h = grams per hour

*Assumes the athlete can tolerate this amount; athletes should experiment with amounts and types of carbohydrates before using in competition.

**The maximal rate of carbohydrate absorption from the gastrointestinal tract is estimated to be 60 g/h. If need approaches or exceeds this amount, it may be helpful to consume sports beverages that contain a variety of sugars, such as glucose, fructose, sucrose, galactose, maltodextrin, isomaltulose, amylose, amylopectin, and/or trehalose.

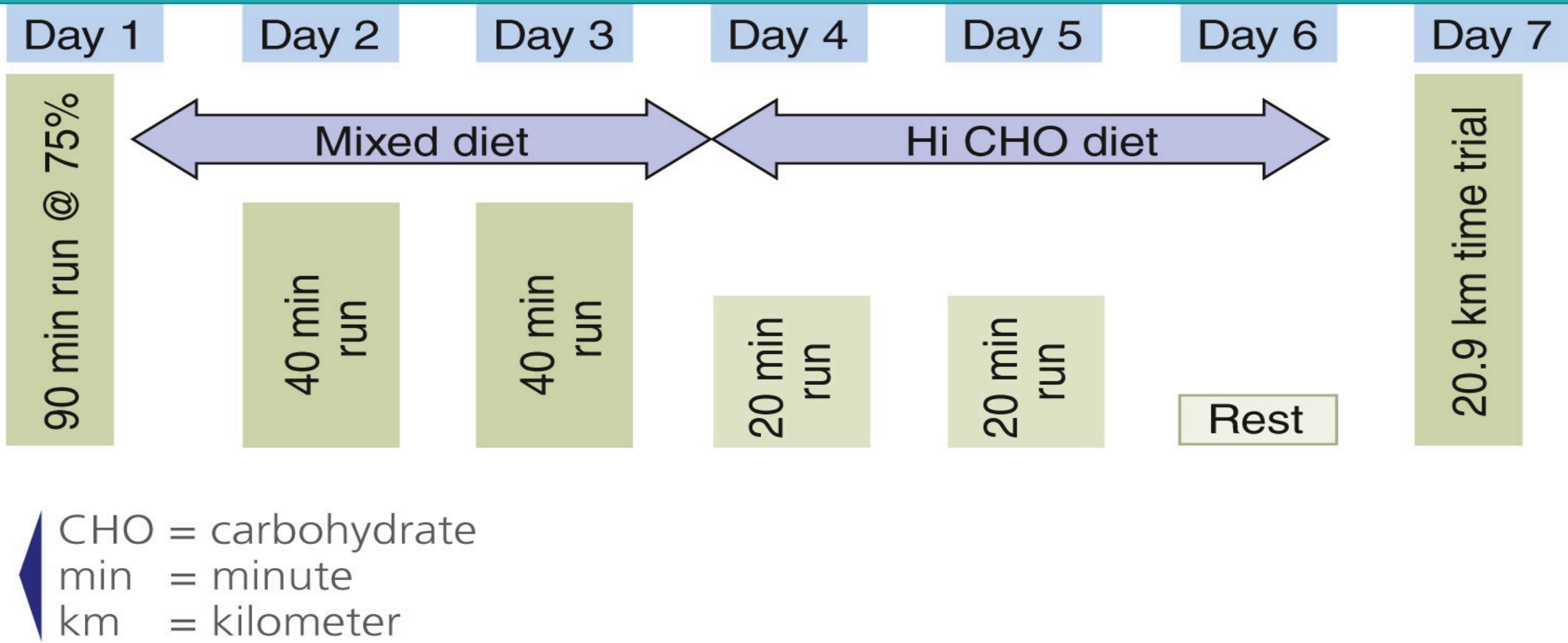
Muscle Glycogen Stores Can Be Maximized by Diet and Exercise Manipulation



CHO = carbohydrate
g/kg/d = grams per kilogram of body weight per day

Drawn from the methods of: Bergström, J., Hermansen, L., and Saltin, B. (1967). Diet, muscle glycogen, and physical performance. *Acta Physiologica Scandinavica, 71*(2), 140–150.

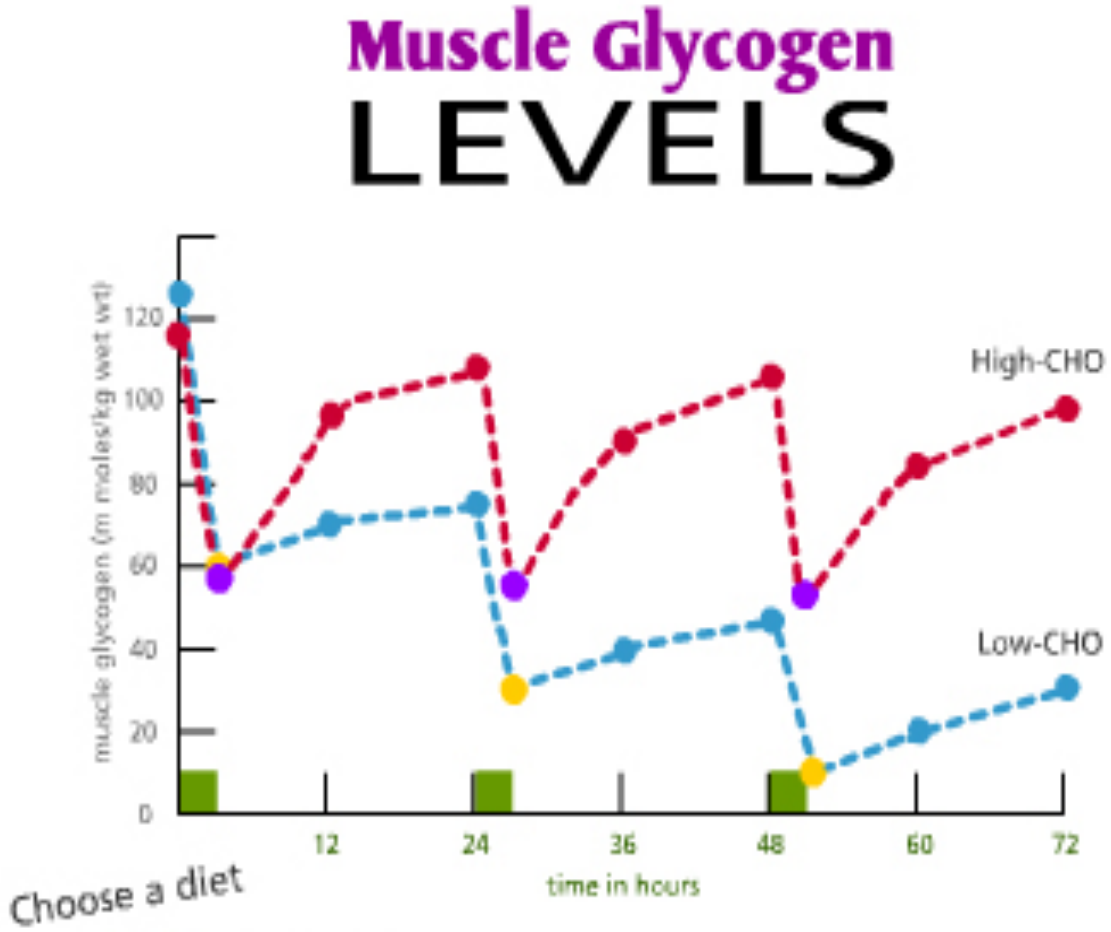
Muscle Glycogen Stores Can Be Maximized by Diet and Exercise Manipulation

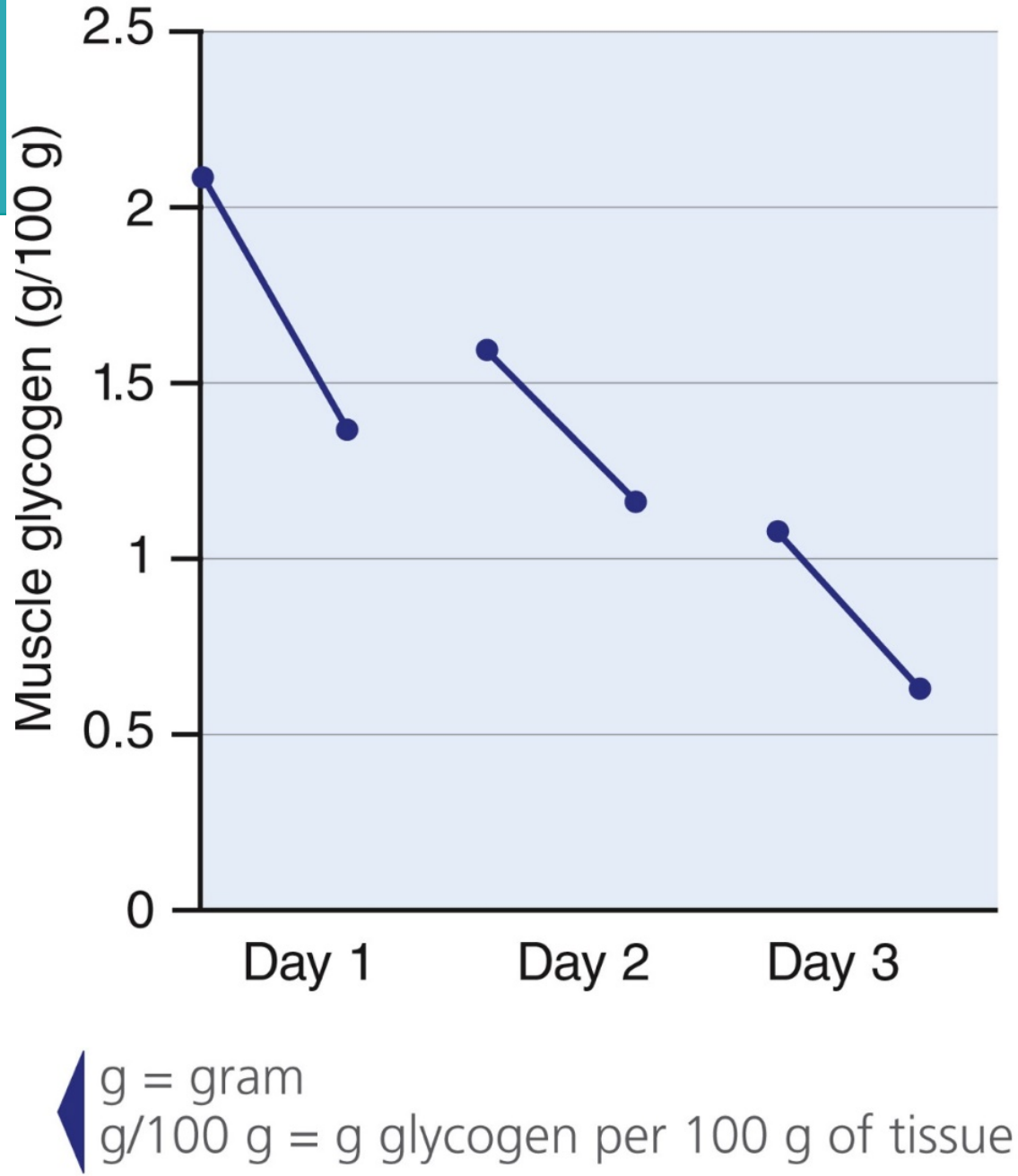


CHO = carbohydrate
min = minute
km = kilometer

Drawn from the methods of: Sherman, W.M., Costill, D.L., Fink, W.J., and Miller, J.M. (1981). The effect of exercise and diet ma-nipulation on muscle glycogen and its subsequent use during performance. *International Journal of Sports Medicine, 2*(2), 114–118.

Training and Performance May Be Impaired





g = gram
g/100 g = g glycogen per 100 g of tissue

Costill, D.L., Bowers, R., Branam, G., and Sparks, K. (1971). Muscle glycogen utilization during prolonged exercise on successive days. *Journal of Applied Physiology, 31*(6), 834–838.

Table 4.10 Estimated Total Daily Carbohydrate Intake in Grams Based on Body Weight

Weight lb (kg*)	5 g/kg	6 g/kg	7 g/kg	8 g/kg	9 g/kg	10 g/kg
85 to 95 (39 to 43)	195–215	234–258	273–301	312–344	351–387	390–430
96 to 105 (44 to 48)	220–240	264–288	308–336	352–384	396–432	440–480
106 to 115 (48 to 52)	240–260	288–312	336–364	384–416	432–468	480–520
116 to 125 (53 to 57)	265–285	318–342	371–399	424–456	477–513	530–570
126 to 135 (57 to 61)	285–305	342–366	399–427	456–488	513–549	570–610
136 to 145 (62 to 66)	310–330	372–396	434–462	496–528	558–594	620–660
146 to 155 (66 to 70)	330–350	396–420	462–490	528–560	594–630	660–700
156 to 165 (71 to 75)	355–375	426–450	497–525	568–600	639–675	710–750
166 to 175 (75 to 79)	375–395	450–474	525–553	600–632	675–711	750–790
176 to 185 (80 to 84)	400–420	480–504	560–588	640–672	720–756	800–840
186 to 195 (84 to 89)	420–445	504–534	588–623	672–712	756–801	840–890
196 to 205 (89 to 93)	445–465	534–558	623–651	712–744	801–837	890–930
206 to 215 (94 to 98)	470–490	564–588	658–686	752–784	846–882	940–980
216 to 225 (98 to 102)	490–510	588–612	686–714	784–816	882–918	980–1,020
226 to 235 (103 to 107)	515–535	618–642	721–749	824–856	927–963	1,030–1,070
236 to 245 (107 to 111)	535–555	642–666	749–777	856–888	963–999	1,070–1,110
246 to 255 (112 to 116)	560–580	672–696	784–812	896–928	1,008–1,044	1,120–1,160
256 to 265 (116 to 120)	580–600	696–720	812–840	928–960	1,044–1,080	1,160–1,200
266 to 275 (121 to 125)	605–625	726–750	847–875	968–1,000	1,089–1,125	1,210–1,250
276 to 285 (125 to 129)	625–645	750–774	875–903	1,000–1,161	1,125–1,161	1,250–1,290

lb = pound; kg = kilogram; g/kg = gram per kilogram of body weight

*Weight in kg is rounded to the nearest whole number.

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Analysis of a 24-Hour Diet of a Male Collegiate Cross Country Runner

Nutrient		Lucas' Goals	Lucas' Intake	Status
Energy	Total Relative	3,400 kcal ~54 kcal/kg	3429 kcal ~54 kcal/kg	Goal met
Carbohydrate	Total Relative	504 g 8 g/kg	515 g 8 g/kg	Goal met
Protein	Total Relative	95 g 1.5 g/kg	129 g 2.0 g/kg	Exceeded goal, but still within guidelines for long distance endurance athletes
Fat	Total Relative	111 g 1.8 g/kg	94 g 1.5 g/kg	Less than goal, but still within guidelines; less fat consumed due to higher protein intake.

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Note: Figures are rounded to the nearest whole number

kcal/kg = kilocalorie per kilogram of body weight; g/kg = gram per kilogram of body weight; g= gram

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Diet Planning for Carbohydrate Intake Must Consider Practical Issues

Table 4.14 Carbohydrate-Containing Foods That Are Easy to Store and Prepare

Carbohydrate-containing food	Storage and preparation tips
Bread or bagels	Keep in freezer. Put in toaster twice.
Waffles	Buy frozen waffles and heat in toaster. Top with syrup or jam.
Pancakes	Buy pourable pancake mix. Add water and cook. Top with syrup or jam.
Cereal	Add shelf-stable (UHT) milk, which does not need refrigeration until it is opened. Cereal can also be used as a topping for yogurt.
Oatmeal or grits	Buy instant oatmeal or grits packages and add hot water.
Pasta	Cook dry or frozen pasta noodles. Heat a jar of tomato-based spaghetti sauce. Combine.
Tortillas (fresh or frozen) and beans (canned)	Spoon canned beans on tortilla (add cheese if desired). Microwave 1 minute. Add salsa and fold.
Fruits	Apples and bananas tend to last longer than fresh berries or stone fruits (for example, peaches or nectarines). If fruits get overripe add to smoothies.
Vegetables	Fresh carrots tend to last a long time when stored in a cool place. Frozen or canned vegetables are easy to store and prepare.
Canned beans	Most kinds of beans can be purchased in cans and only need to be reheated.
Milk	Milk that has been processed using ultrahigh temperature (UHT) pasteurization can remain on the shelf until opened.
Frozen entrees	Several brands specialize in "healthy" frozen entrees that contain high-carbohydrate, moderate-protein, low-fat, and low-sodium meals.
Nuts	Unopened jar or cans can remain on the shelf; after opening nuts can be stored in the freezer.

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Sugar Intake and the Use of Artificial Sweeteners

Table 4.15 Artificial (Nonnutritive) Sweeteners

Artificial sweetener	Description
Acesulfame potassium (Acesulfame K or Sunett®)	• Often mixed with other artificial sweeteners such as aspartame
Aspartame (Nutrasweet®, Equal®)	• Made of two amino acids, L-aspartic acid and L-phenylalanine • Warning label is required because those with phenylketonuria cannot metabolize the phenylalanine • FDA approved. Opponents question its safety on the basis that it causes seizure, headache, memory loss, and mood change.
Neotame	• Intensely sweet (7,000 to 13,000 times sweeter than sugar)
Saccharin (Sweet 'n Low®)	• Oldest artificial sweetener (discovered in 1879) • Once thought to be a cause of bladder cancer, but studies in humans do not support this association • Often found in restaurants as single-serving packets
Stevia	• Herb known for its sweet-tasting leaves • May have a beneficial effect on blood glucose and insulin levels
Sucralose (Splenda®)	• Derived from sugar but is not digestible because of the substitution of three chlorine atoms for three OH groups • Also contains maltodextrin, a starch, which gives it bulk so that it will measure like sugar in recipes

O = Oxygen; H = Hydrogen

Source: Academy of Nutrition and Dietetics. 2012. Position paper: Use of nutritive and nonnutritive sweeteners. *Journal of the Academy of Nutrition and Dietetics, 112,*739–758. Erratum in *112,* 1279.

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Summary

- Carbohydrates are the primary energy source for moderate to intense exercise
- Exercise reduces glycogen stores, which must be replenished on a daily basis
- The general recommendation for carbohydrate intake for athletes in training is 5 to 12 g/kg of body weight daily
- Carbohydrate loading is one technique that endurance athletes and some bodybuilders use before an important competition

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Summary

- Sufficient carbohydrate intake is an important element in athletic training and competition
- Some athletes have lactose intolerance, reactive hypoglycemia, or diabetes, and these conditions influence the choice of carbohydrate containing foods
- Proper carbohydrate intake positively affects training, recovery, performance, and health

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