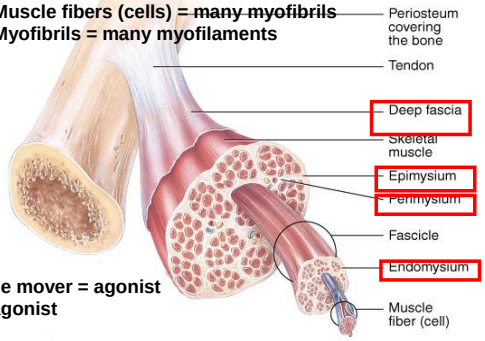
Chapter 12 Outline

- Skeletal Muscles
- Mechanisms of Contraction
- Contractions of Skeletal Muscle
- Energy Requirements of Skeletal Muscle
- Neural Control of Skeletal Muscles
- Cardiac and Smooth Muscle

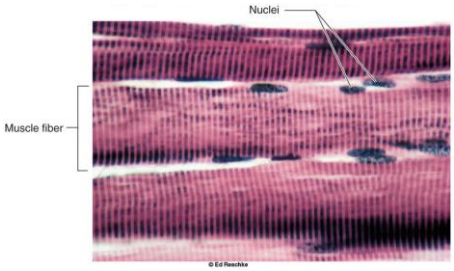
Muscle = many fasciles
Fascicles = many muscles fibers (cells)
Muscle fibers (cells) = many myofibrils
Myofibrils = many myofilaments



Prime mover = agonist
Antagonist

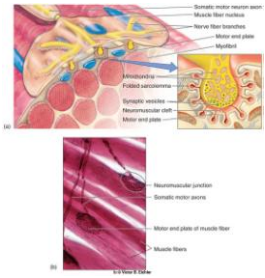
Skeletal Muscle Structure

- Most distinctive feature of skeletal muscle is its striations



Neuromuscular Junction (NMJ)

- Synaptic ending of motor neuron that innervates a muscle fiber
- Motor end plate = right where junction occures



Motor Units

- **motor unit – one nerve fiber and all the muscle fibers innervated by it**
- **All or none – all fibers contract**
- **Avg. ~ 200 muscle fibers per motor unit**
- **small motor units - fine degree of control**
- **large motor units – more strength than control**
  - **powerful contractions supplied by large motor units**

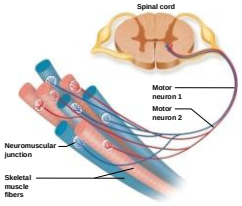
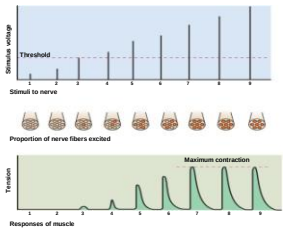


Figure 11.6

Motor Unit

- If individual motor units fire "all-or-none," how do skeletal muscles perform smooth movements?
  - Recruitment!!!!:
    - Brain estimates number of motor units required and stimulates them to contract
    - keeps recruiting more units until desired movement is accomplished in smooth fashion
    - More and larger motor units are activated to produce greater strength

Recruitment and Stimulus Intensity



- stimulating nerve with higher and higher voltages produces stronger contractions (more nerve cells excited = more motor units stimulated)
- recruitment of multiple motor unit (MMU) summation – the process of bringing more motor units into play

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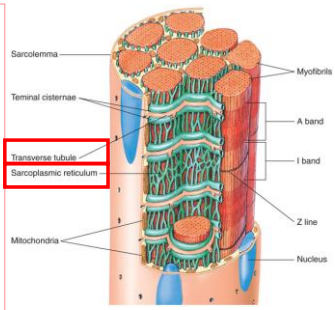
Structure of Muscle Fiber

- Each fiber is packed with myofibrils
  - Myofibrils: 1μ in diameter and extend length of fiber
    - Packed with myofilaments
      - Actin & Myosin



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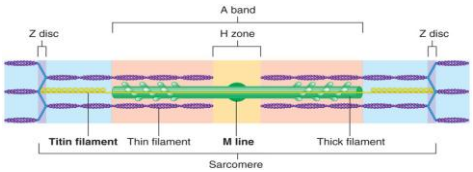
Sarcomeres

- The Functional Units of Skeletal and Cardiac muscle
- Contractile units (**actin & myosin**) between 2 Z discs (Structural proteins)
- M lines: structural proteins that anchor myosin
- Titin Structural proteins attaching myosin to Z disc



- Troponin & Tropomyosin (aka T-T Complex)

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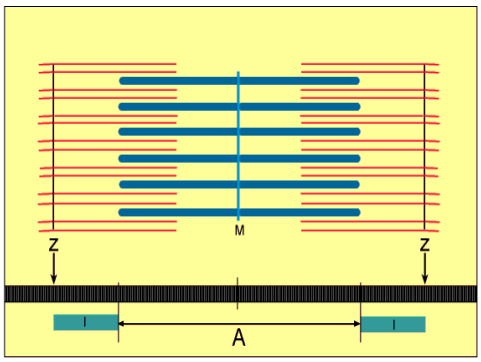

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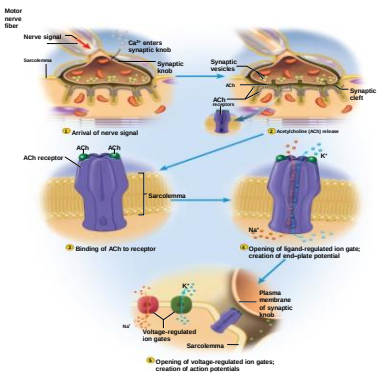
Excitation of a Muscle Fiber



Excitation-Contraction Coupling

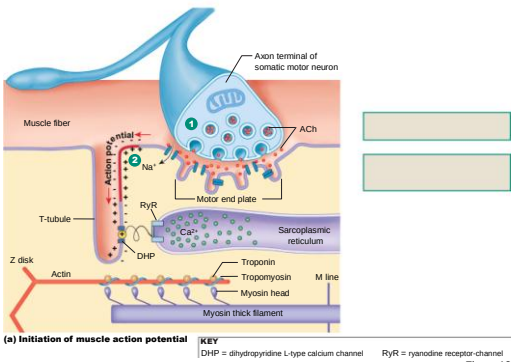
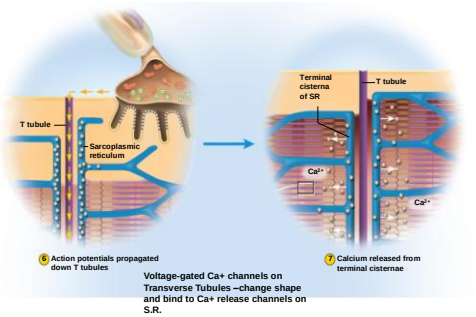


Figure 12-11a

Excitation-Contraction Coupling



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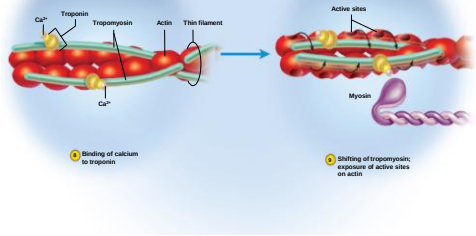
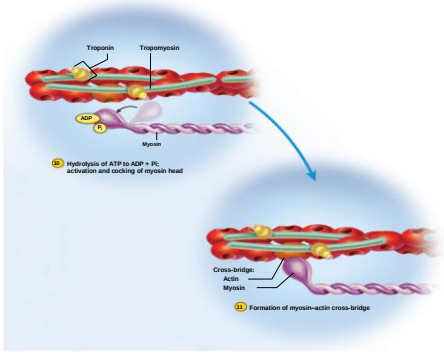
Excitation-Contraction Coupling

Process in which APs initiate Ca+ signals that activate a contraction-rleaxation cycle

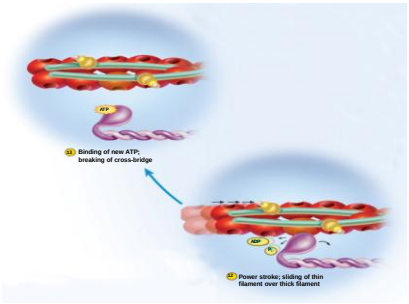


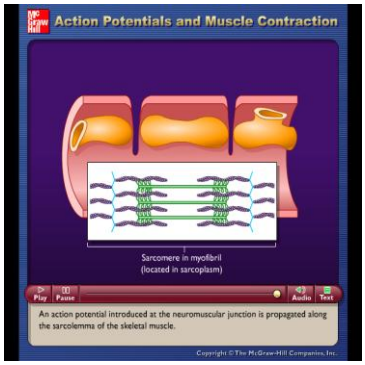
11-14

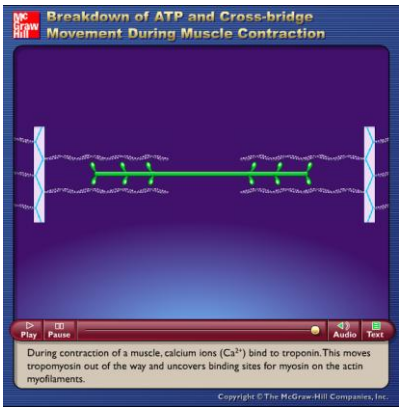
Contraction



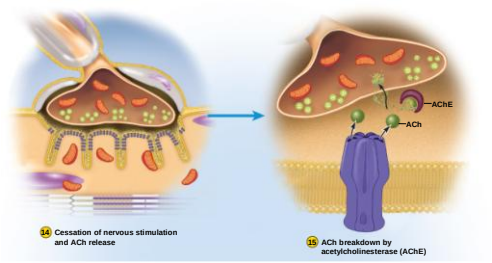
Contraction







Relaxation



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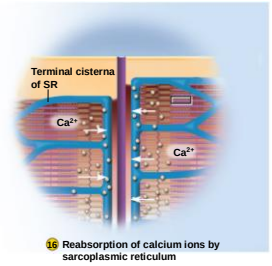
Relaxation



- Ca^{+2} pumped back into SR by active transport.
- ATP is needed for muscle relaxation as well as muscle contraction!

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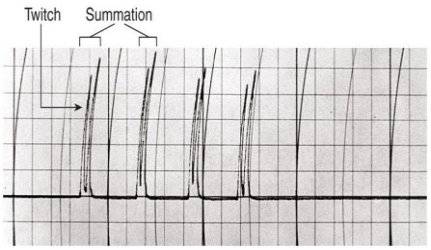
Twitch & Summation

- **Twitch: A single contraction/relaxation of a muscle fiber**
- **Summation: Occurs if 2nd stimulus occurs before muscle relaxes from 1st stimulus**



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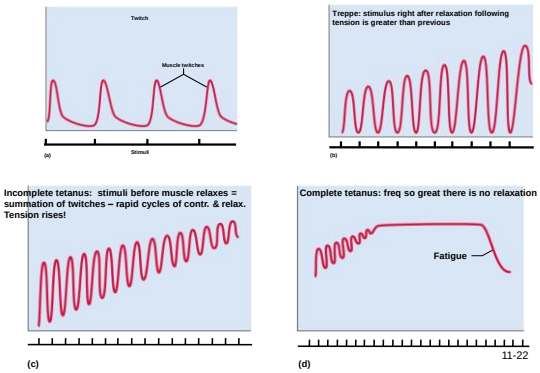
Twitch Strength & Stimulus Frequency



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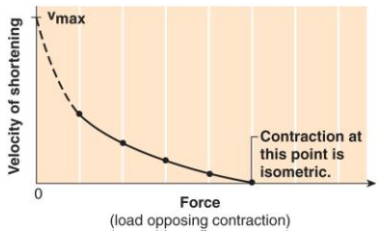
Velocity of Contraction

- For muscle to shorten it must generate force greater than the load
- The lighter the load the faster the contraction and vice versa



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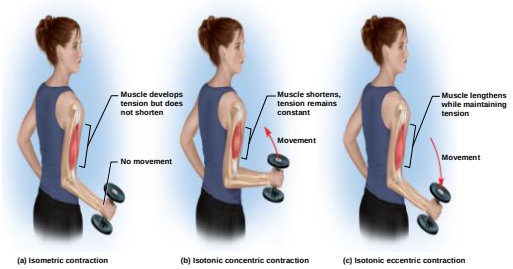

Length-Tension Relationship

- Strength of muscle contraction influenced by:
  - No. fibers in muscle that are stimulated
  - Frequency of stimulation
  - Thickness of each muscle fiber
  - **Initial length of muscle fiber (how stretched or contracted it is when stimulated)**
    - Ideal resting length is that which can generate maximum force

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Length-Tension Relationships in Contracting Skeletal Muscle

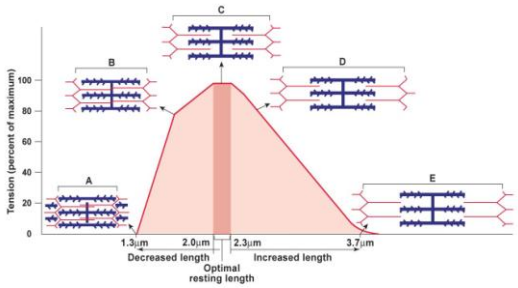
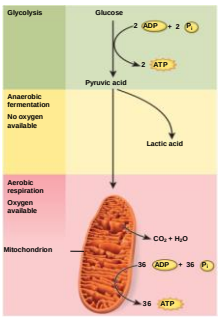


Figure 12-16

Muscle Metabolism

- all muscle contraction depends on ATP
- ATP supply depends on availability of:
  - oxygen
  - organic energy sources (e.g., glucose and fatty acids)
- two main pathways of ATP synthesis
  - Anaerobic
  - Aerobic



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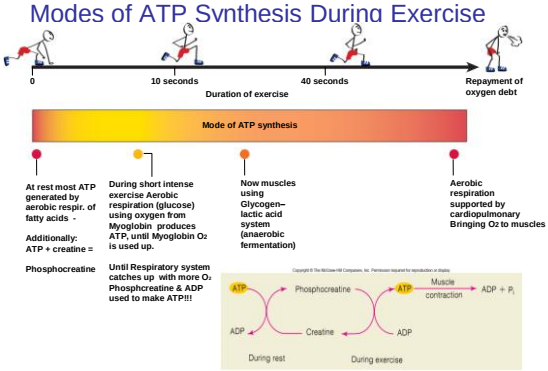
Modes of ATP Synthesis During Exercise



Metabolism of Skeletal Muscles

- During light exercise, most energy is derived from aerobic respiration of fatty acids
- During moderate exercise, energy derived equally from fatty acids and glucose
- During heavy exercise, glucose supplies 2/3 of energy
  - Liver increases glycogenolysis
  - GLUT-4 carrier is moved to muscle cell's plasma membrane

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Physiological Classes of Muscle Fibers

- **slow oxidative (SO), slow-twitch, red, or type I fibers**
  - **abundant mitochondria, myoglobin and capillaries - deep red color**
    - **adapted for aerobic respiration and fatigue resistance**
      - **relative long twitch lasting about 100 msec**
- **fast glycolytic (FG), fast-twitch, white, or type II fibers**
  - **well adapted for quick responses, but not fatigue resistant**
  - **rich in enzymes of phosphagen and glycogen-lactic acid systems generate lactic acid causing fatigue**
  - **Few mitochondria, myoglobin, and blood caps = pale appearance**

11-30

Fatigue

- muscle fatigue - progressive weakness and loss of contractility from prolonged use of the muscles
- causes of muscle fatigue
  - ATP synthesis declines as glycogen is consumed
  - ATP shortage slows down the Na^+ - K^+ pumps
  - lactic acid lowers pH of sarcoplasm
    - inhibits enzymes involved in contraction, ATP synthesis
  - release of K^+ with each action potential causes the accumulation of extracellular K^+
    - hyperpolarizes the cell and makes the muscle fiber less excitable
  - motor nerve fibers use up their Ach
  - central nervous system fatigues ???????, so there is less signal output to the skeletal muscles

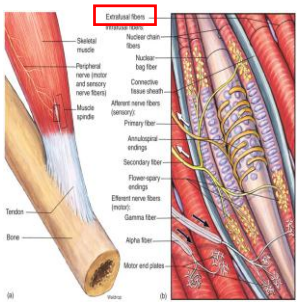
Neural Control of Skeletal Muscles

- Motor neuron cell bodies are in spinal cord; axons leave via ventral root (aka lower motor neurons)
  - Activity influenced by sensory feedback from muscles and tendons:
    1. Golgi tendon organs (tension on tendons)
    2. Muscle spindle apparatus (length of muscle detector)

Excitatory and inhibitory activity from upper motor neurons & interneurons.

Muscle Spindle Apparatus (sensory)

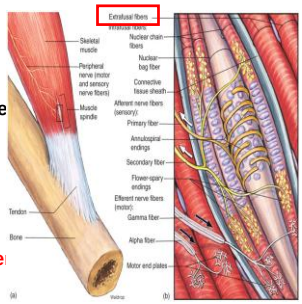
- Consists of modified thin muscle cells:
- intrafusal fibers: (packaged w/in CT sheath)
  - No myofibrils in middle
- extrafusal fibers: regular cells outside of spindle app.
- Both insert into tendons



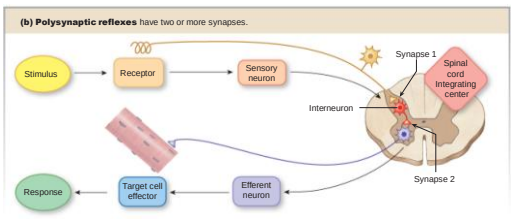
Muscle Spindle Apparatus (sensory)

- Sensory Neurons:
  - Detect stretching of Spindle App.
- Motor Neurons:
  - α motor neurons stimulate extrafusal fibers (shorten muscle)
  - gamma motor neurons causes intrafusal fibers (spindle to tighten only at ends)
  - usually stimulated in conce

Golgi Tendon organs:
- monitor tension on tendons
- synapse w interneurons (IPSP)



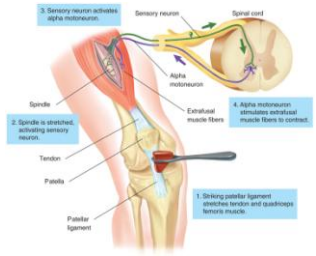
Somatic Motor Reflexes



Autonomic visceral reflexes – 2 efferent neurons

Figure 13-1b

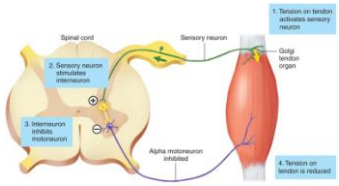
Monosynaptic-Stretch Reflex



Golgi Tendon Organ Reflex

- Involves 2 synapses in CNS
- Sensory axons from Golgi tendon organ synapse on interneurons
  - Which make inhibitory synapses on motor neurons
- Prevents excessive muscle contraction or passive muscle stretching

(=disynaptic reflex)



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Patellar Tendon (Knee Jerk) Reflex

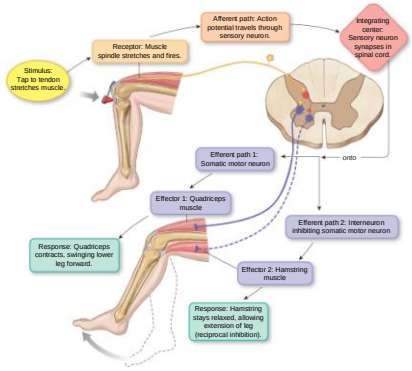


Figure 13-7

Flexion Reflex and the Crossed Extensor Reflex

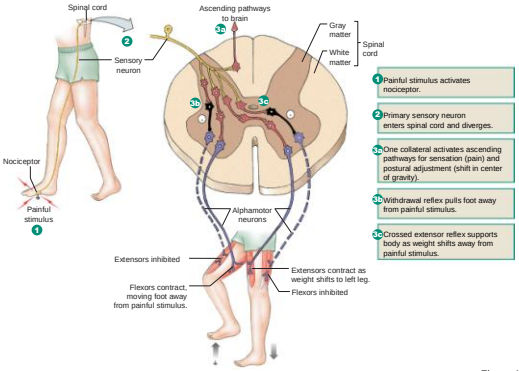


Figure 13-8

CNS Control of Voluntary Movement

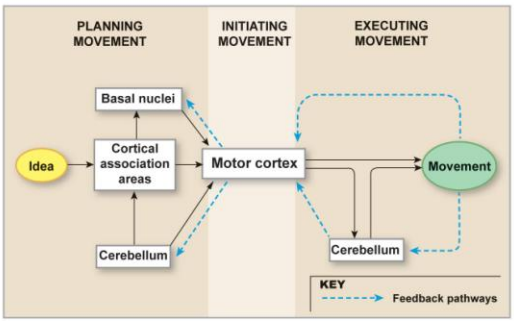


Figure 13-10

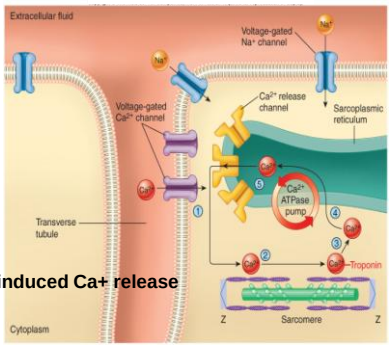
Cardiac muscle

- Characteristics?
- Heart muscle = myocardium
- Gap junctions (intercalated discs)
- Sinoatrial node (pacemaker) – group of autorythmic cells
  - i.e., heart cells don't require outside stimulation

  But:
  - Frequency of HB can be influenced by epinepherine
  - Frequency of HB can be influenced by streching chambers

12-75

Cardiac Muscle (Myocardium)



- **Ca+ induced Ca+ release**

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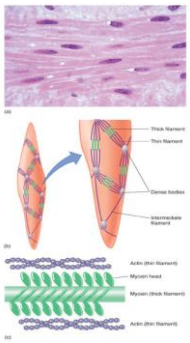
Smooth Muscle

- Characteristics?
- Often circular/longitudinal arrangement
- No sarcomeres!
- Has no Troponin!!!!!!!!!
- Has gap junctions
- Contains more actin than myosin
  - Allows greater stretching and contracting
- Actin filaments are anchored to dense bodies (like z-discs)
- Can have graded depolarizations (contractions)



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Smooth Muscle Contraction

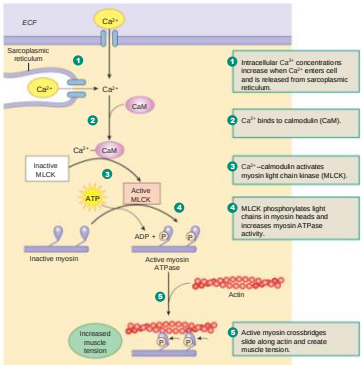
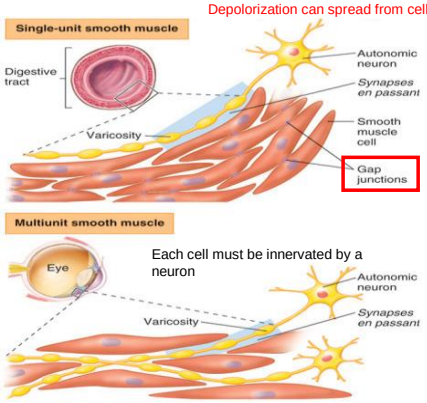


Figure 12-28

Depolorization can spread from cell to cell



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