38.4D: ATP and Muscle Contraction

ATP is critical for muscle contractions because it breaks the myosin-actin cross-bridge, freeing the myosin for the next contraction.

Learning Objectives

• Discuss how energy is consumed during movement

Key Points

• ATP prepares myosin for binding with actin by moving it to a higher-energy state and a “cocked” position.
• Once the myosin forms a cross-bridge with actin, the Pi disassociates and the myosin undergoes the power stroke, reaching a lower energy state when the sarcomere shortens.
• ATP must bind to myosin to break the cross-bridge and enable the myosin to rebind to actin at the next muscle contraction.

Key Terms

• M-line: the disc in the middle of the sarcomere, inside the H-zone
• troponin: a complex of three regulatory proteins that is integral to muscle contraction in skeletal and cardiac muscle, or any member of this complex
• ATPase: a class of enzymes that catalyze the decomposition of ATP into ADP and a free phosphate ion, releasing energy that is often harnessed to drive other chemical reactions
ATP and Muscle Contraction

Muscles contract in a repeated pattern of binding and releasing between the two thin and thick strands of the sarcomere. ATP is critical to prepare myosin for binding and to “recharge” the myosin.

The Cross-Bridge Muscle Contraction Cycle

ATP first binds to myosin, moving it to a high-energy state. The ATP is hydrolyzed into ADP and inorganic phosphate (P_i) by the enzyme ATPase. The energy released during ATP hydrolysis changes the angle of the myosin head into a “cocked” position, ready to bind to actin if the sites are available. ADP and P_i remain attached; myosin is in its high energy configuration.

Figure 1: Cross-bridge muscle contraction cycle: The cross-bridge muscle contraction cycle, which is triggered by Ca^{2+} binding to the actin active site, is shown. With each contraction cycle, actin moves relative to myosin.

The muscle contraction cycle is triggered by calcium ions binding to the protein complex troponin, exposing the active-binding sites on the actin. As soon as the actin-binding sites are uncovered, the high-energy myosin head bridges the gap, forming a cross-bridge. Once myosin binds to the actin, the P_i is released, and the myosin undergoes a
conformational change to a lower energy state. As myosin expends the energy, it moves through the “power stroke,” pulling the actin filament toward the M-line. When the actin is pulled approximately 10 nm toward the M-line, the sarcomere shortens and the muscle contracts. At the end of the power stroke, the myosin is in a low-energy position.

After the power stroke, ADP is released, but the cross-bridge formed is still in place. ATP then binds to myosin, moving the myosin to its high-energy state, releasing the myosin head from the actin active site. ATP can then attach to myosin, which allows the cross-bridge cycle to start again; further muscle contraction can occur. Therefore, without ATP, muscles would remain in their contracted state, rather than their relaxed state.