A missense mutation makes a mess of Ca^{2+} sensing

Caitlin Sedwick

A new JGP study shows how a disease-causing mutation in RyR2 dramatically alters channel behavior.

The human heart beats more than 2.5 billion times over the course of an average lifetime. The ryanodine receptor type 2 (RyR2) helps regulate these beats, and mutations in this ion channel cause catecholamine-induced polymorphic ventricular tachycardia (CPVT). Uehara et al. describe how one particular disease-causing mutation dramatically affects RyR2 behavior.

The arrival of a cardiac action potential allows extracellular Ca^{2+} to enter the cell and bind to RyR2 channels embedded in the membrane of the endoplasmic reticulum (called the sarcoplasmic reticulum, or SR, in muscle cells), causing the channels to open and release Ca^{2+} from the SR into the cytoplasm. The resultant rise in cytoplasmic Ca^{2+} activates the cardiomyocyte’s actomyosin contractile apparatus and also jumpstarts mechanisms that pump Ca^{2+} back out of the cytoplasm to prepare the cell for the arrival of the next action potential.

Mutations in human RyR2 can allow excessive SR Ca^{2+} leak, provoking contractions out of sync with cardiac action potentials and causing CPVT patients to develop an abnormally rapid heartbeat in response to exercise or stress (2). A 2009 study (3) identified a young girl with a point mutation in one of her RyR2 alleles that replaced the lysine residue at amino acid 4750 with a glutamine residue. “The patient harboring this mutant RyR2 was extremely leaky,” says Dr. Akira Uehara, from Fukuoka University in Japan. “Our imaging experiment confirmed that RyR2-K4750Q also opens at lower SR luminal Ca^{2+} levels than wild type and remains open even at high Ca^{2+} levels. Single-channel studies confirmed that RyR2-K4750Q also opens at lower SR luminal Ca^{2+} levels than do wild-type channels. “We were amazed at the dramatic alteration in all three RyR2 Ca^{2+} sensitivity mechanisms induced by this single missense point mutation,” says Uehara.

“We were amazed at the dramatic alteration in all three RyR2 Ca^{2+} sensitivity mechanisms.”

What explains the leakiness of the mutant channels? Recent physiological and modeling studies (4) suggest that Ca^{2+} governs RyR2’s transmembrane pore in multiple ways. First, although its transmembrane pore is mostly closed to ion traffic in the absence of Ca^{2+}, researchers think that RyR2 opens when Ca^{2+} binds to an activation site on the cytoplasmic face of the channel. Second, Ca^{2+} can also bind to another, lower-affinity site on RyR2 and destabilize the channel’s open state. Therefore, RyR2 channels are mostly open at intermediate levels of cytoplasmic Ca^{2+} but mostly closed at very low or very high cytoplasmic levels. Finally, wild-type RyR2 can open in response to high SR luminal Ca^{2+}, which can act via intra-SR mechanisms (5) and/or pass through the channel to activate neighboring RyR2s (6).

Uehara and colleagues found that the K4750Q mutation makes RyR2 much more sensitive to Ca^{2+} activation and simultaneously abolishes Ca^{2+} inactivation. Therefore, the channel opens at lower Ca^{2+} levels than wild type and remains open even at high Ca^{2+} levels. “We were amazed at the dramatic alteration in all three RyR2 Ca^{2+} sensitivity mechanisms induced by this single missense point mutation,” says Uehara.

Uehara et al. theorize that the lysine at 4750 may help stabilize RyR2’s closed conformation by forming salt bridges with nearby charged amino acids—interactions that could be lost upon substitution of a neutral residue such as glutamine. Functional studies are already underway to test this, and Uehara invites collaborations on structural studies to learn more about how K4750Q affects RyR2 activity.