Minimizing Caribbean Tsunami Risk
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acquire stiffness optima as an emergent property of the physical and biochemical interactions between their constituent cells. This tensional equilibrium confers macroscopic compliance properties that are critical for processes such as stem cell differentiation, embryonic development, and tissue homeostasis.

The specific mechanisms by which individual cells physically remodel themselves to functionally drive macroscopic changes in tissue compliance are not well understood, however. In addition to responding dynamically to immediate physical cues, cells must operate on long time scales to promote phenotypic stabilization, likely by directing transcriptional and epigenetic changes.

Swift et al. show that the relative abundance of lamin A is a key component of mechanoreciprocal responses and a major determinant of cell and tissue stiffness (see the figure). The authors observed that increased cell tension reduces the turnover of lamin A in the nuclear lamina. This causes accumulation of the mechanosensitive Yes-associated protein (YAP), a master transcriptional regulator. An increase in lamin A also triggers the serum response factor (SRF) signaling pathway, whose gene targets control the actin cytoskeleton. The accumulation of lamin A also drives translocation of the retinoic acid receptor into the nucleus to stimulate transcription of LMNA and the production of more lamin A. The findings suggest a mechanism that could explain the strong correlation between relative abundance of lamin A in diverse cell types with macroscopic tissue stiffness. Interestingly, as the relative abundance of lamin A increases, the viscosity of the nucleus also increases. It is possible that in addition to activating mechanosignaling pathways, an increase in lamin A may play a role in physically stiffening the nucleus as part of the cellular response to increased tension.

The model presented by Swift et al. proposes how cells that are otherwise acutely sensitive to mechanical signals can structurally acclimate to tissue environments that are pervasively subject to a sizable mechanical load. In such circumstances, lamin A could physically reinforce the nuclear envelope, which would stabilize interactions between chromatin and the nuclear lamina and inure the cell to subsequent nuclear distortions that might otherwise occur in a high-tension tissue environment. Indeed, such an observation could explain why many tumors, which are typically stiffer than the surrounding tissue and are characterized by increased interstitial pressure, also often have greater amounts of lamin A compared to normal cells (6, 7). Moreover, the model hints at a deeper interplay between mechanosensitive signaling pathways, which are apparently affected by both external stress and elevated lamin A abundance, and transcriptional changes that are induced by direct tension on the nucleus from cytoskeletal contacts, which are likely to be modified in cells with lamin A–rich nuclear envelopes. Alternatively, increased tissue-level stiffness might compensate for lamin A–induced changes in nuclear compliance, such that the cytoskeleton simply transmits a greater mechanical load to enable cytoskeletal contact points on the nucleus to remain mechanically sensitive.

The provocative feed-forward mechanism governing lamin A concentration in the model of Swift et al. is critically dependent on retinoic acid receptor activity and provides another potential layer of mechanosensitive regulation. For instance, in the absence of ligand, the retinoic acid receptor will heterodimerize with one of the nuclear receptor core–repressor repressor proteins which, together with their associated histone deacetylases, inhibits transcription from specific promoters to maintain heterochromatin. Given the importance of the nuclear lamina in stabilizing heterochromatin, the data presented by Swift et al. implicate epigenetic silencing of lamina-associated chromatin as a key component of tension-mediated transcriptional regulation.

Additional studies are required to explicitly link mechano-reciprocal nuclear stiffening to gene–regulatory mechanisms. Elucidating the phenomena that collectively define cellular mechanosensation will also require studies to more completely unify the functionality of direct and indirect force-mediated transcriptional mechanisms. For cells, it seems that tension can become a source of considerable strength.

References

GEOPHYSICS

Minimizing Caribbean Tsunami Risk

Christa von Hillebrandt-Andrade

Efforts to understand and respond to tsunami risks in the Caribbean are beginning to bear fruit.

In the past 500 years, more than 75 tsunamis have been documented in the Caribbean and adjacent regions. Since 1842, 3446 people are reported to have perished to these killer waves. The tsunami generated by the 2010 Haiti earthquake claimed several lives, but the most recent devastating events were the 1946 tsunamis of the Dominican Republic, with at least 1800 victims (1). Since then, there has been an explosive increase in residents, visitors, infrastructure, and economic activity along Caribbean coastlines, increasing the potential for human and economic loss. On any day, more than 500,000 people could be in harm’s way along the beaches (2), with hundreds of thousands more working and living in the tsunami hazard zones.

In the Caribbean, most tsunami events are very short-fused: The waves can reach the shores within minutes of an earthquake, volcanic eruption, or submarine landslide. Addressing this threat requires a very effective monitoring and warning system, as well as a public that is acutely aware of the natural signs of an impending tsunami. The current performance goal is that earthquakes with moment magnitudes M 7.3 in the Caribbean should be detected within a minute and that the tsunami warning centers issue a message within 5 min, which is immediately relayed by the local authorities to the public in case of threat (3). Tsunami evacuation maps

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Early warning required. Tsunamis up to 10 m in height have been observed throughout the Caribbean; many reach shores within minutes. An extensive network of National Ocean Service, GLOSS (Global Sea Level Observing System) and other coastal sea level stations, DART (Deep Ocean Assessment and Reporting of Tsunamis) buoys, COCONet GPS stations, and seismic stations contributes to the local tsunami and coastal hazards warning system CARIBE EWS. [Data from NOAA/National Geophysical Data Center]

Indicate where people should move to in the case of a tsunami event. Land-use planning and protection of coastal resources are also important for mitigating tsunami impacts.

Since the mid-1990s, the Intergovernmental Oceanographic Commission of UNESCO has advocated the development of a Caribbean tsunami warning system. In the wake of the 2004 Indian Ocean tsunami, it succeeded in establishing an intergovernmental coordination group tasked with developing a tsunami and other coastal hazards warning system for the Caribbean and adjacent regions (CARIBE EWS) (4). The CARIBE EWS includes 32 member states and 16 territories and commonwealths (see the figure).

In 2006, when the CARIBE EWS met for the first time, there were just a dozen seismic stations, a handful of sea level stations, some tsunami inundation maps, a few educational resources, one country with a tsunami warning protocol, and no evacuation maps in the region.

Similar to other tsunami-sensitive regions in the world, the tsunami detection capabilities have increased dramatically since then. Although seismic data are used to detect earthquakes that could generate tsunamis, sea level data are currently used to both confirm the size of the tsunami and forecast its impact. Today, there are more than 115 seismic and 55 sea level stations in the Caribbean and adjacent regions (see the figure). Global Positioning System (GPS) data could also help to provide accurate and timely tsunami warnings (5). The CARIBE EWS has endorsed projects like the Continuously Operating Caribbean GPS Observational Network (COCONet), which has already installed, refurbished, or made available data from more than 84 GPS stations in the region (6). The augmentation of observational data has helped reduce the detection time of earthquakes by 3 to 4 min to 1 min (7).

Unlike the UNESCO regional tsunami warning systems for the Pacific and Indian Oceans and the Northeastern Atlantic and Mediterranean, no Tsunami Warning Center has yet been established in the Caribbean. Nevertheless, forecasts and warnings are being provided on an interim basis by the U.S. National Weather Service (NWS) Tsunami Warning Centers in Alaska and Hawaii. In 2010, the NWS established the Caribbean Tsunami Warning Program (CTWP) in Mayagüez, Puerto Rico, as part of its three-phased approach to the establishment of a tsunami warning center in the region. Given significant advances in phases one (education) and two (monitoring), NOAA is currently evaluating whether to proceed with phase three and establish a Regional Tsunami Warning Center at the University of Puerto Rico Mayagüez or to consider proposing an alternative end state that also ensures an equal or improved level of service.

Tsunami inundation and evacuation maps help guide people to safety during a tsunami emergency. These maps require as input detailed information on tsunami sources, as well as high-resolution digital elevation models (DEMs). Only a few of the countries in the region have had the resources to undertake this work. Efforts are underway to develop a database on tsunami sources and improve the DEMs that could also be used for other hazard and risk studies.

Currently 94% of all countries and territories of the Caribbean have a designated tsunami contact and warning points for coordinating the system and issuance of alerts. Tsunami exercises are conducted to test communication between warning centers, warning points, and the public, as well as practice and review emergency response procedures. Regional exercises were conducted in 2011 and 2013. For the 2013 exercise, almost 50,000 people and 500 organizations participated from 45 of the countries and territories in the region. Given the success of these exercises in helping to identify and correct deficiencies and sharing of best practices, it has been decided that such exercises should be conducted annually (8).

Community-based recognition programs help to motivate, harmonize, and track readiness. One such initiative is the TsunamiReady Program of the NWS, also supported internationally as a pilot project with the Intergovernmental Oceanographic Commission (IOC). The program requires the designated communities to have 24/7 warning capabilities, evacuation maps and signs, exercise and outreach activities, and emergency response plans. In addition to more than 30 coastal communities in Puerto Rico, Anguilla was the first non-U.S. jurisdiction.
A Clear Advance in Soft Actuators

John A. Rogers

Development of actuator technologies with capabilities that can match or exceed those found in biology represents a topic of long-standing interest within the advanced robotics community. One promising and remarkably simple class of such an “artificial muscle” exploits a dielectric elastomer (an electrical insulator) sandwiched between a pair of mechanically compliant electrodes (1, 2). Electrostatic force generated by an applied voltage deforms the dielectric and causes rapid, controlled displacements with large amplitudes. On page 984 of this issue, Keplinger et al. (3) describe an important advance in this dielectric elastomer actuator (DEA) technology, in which the authors replace the electrodes with soft, transparent hydrogels. The result provides a clever solution to a daunting materials challenge; it enables delivery of high voltages for fast, effective operation without any mechanical constraint on the motions of the dielectric, in a form that also provides almost perfect optical transparency.

Films of carbon powder or grease loaded with carbon black served as electrodes for the earliest DEAs (1, 2). Although valuable for initial prototypes, such materials have poor reliability and are not readily compatible with established manufacturing techniques. Improved characteristics can be achieved with alternatives based on sheets of graphene (4), coatings of carbon nanotubes (5), surface-implanted layers of metallic nanoclusters (5), and corrugated or patterned films of metals (5). These options yield working DEAs, but with limited mechanical properties, sheet resistances, switching times, and capacity to integrate into advanced actuator designs. The authors show that a different class of material (soft, transparent hydrogels) and a different mode of charge transport (ionic, rather than electronic) can yield electrodes with characteristics that are remarkably well suited for use in DEAs. A key but nonobvious realization is that even aqueous ionic hydrogels can deliver potentials of several kilovolts, despite the onset of water electrolysis at less than 1.5 V.

The physics is relatively simple. A potential applied to a conductor in contact with a hydrogel induces ionic transport that yields a net charge at the interface together with an adjacent screening charge, known collectively as an electric double layer. A cor-