Synthetic gels to protect the brain against traumatic injuries

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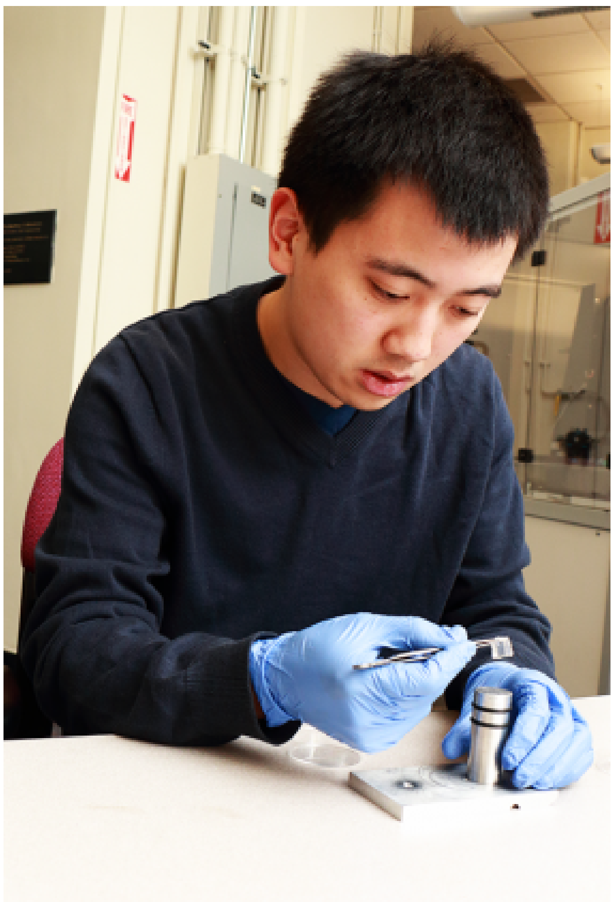

MIT biological engineering graduate student Bo Qing demonstrates how he loads a polydimethylsiloxane gel onto a post used in a nanoindenter to measure the gel's impact response. The instrument in the NanoMechanical Technology Lab at MIT pushes an indenter into the gel material, which is designed to mimic brain tissue, at very high loading rates. The work is part of a study under Associate Professor Krystyn Van Vliet, in conjunction with the U.S. Army Research Lab and Institute for Soldier Nanotechnology at MIT. Credit: Denis Paiste/Materials

Designing better protective gear against severe impacts for civilians and soldiers requires a detailed understanding of how soft tissues in the body actually respond to such impacts, whether from concussions, ballistic attacks, or blast wounds. MIT researchers are developing new synthetic polymer-solvent gels, called tissue simulant gels, which mimic the response of natural tissue.

Biological engineering graduate student Bo Qing is studying the impact of traumatic force on brain tissue from rodents and modeling synthetic substitutes to enable better insight into preventing such injuries. "If we can design a material that mimics this impact response, it would be very helpful to serve as an injury model and use to assess new protective equipment that can minimize this harm," explains Qing, who works under MIT Associate Professor Krystyn J. Van Vliet.

"We want to study how biological tissues like the brain, heart, and liver respond to impact and then find synthetic mimics that can recapitulate those responses because they will be very helpful for the Army, for example, to devise new protective strategies and understand how injury actually occurs," Qing says.

Qing is studying multilayered polydimethylsiloxane-based (PDMS) gels, which are stretchy and transparent, as models for brain tissue. The Van Vliet group previously identified specific cross-linked PDMS gel compositions that closely matched the impact response of heart tissue.

"These are, essentially, a PDMS chemically cross-linked network, that's loaded with a PDMS solvent. There are a lot of different variations of these gels where we can basically tune the cross-linker-to-polymer-base stoichiometric ratio, the molecular weight of the PDMS solvent, and the amount of solvent that's used for these different type of gels," Qing says.

The work is supported by the U.S. Army Research Lab, which provides some of the organogels. Qing synthesizes the top layer using a different commercially available type of PDMS without the solvent. "In terms of that top layer, some properties I'm varying are its stiffness as well as its thickness to tune the overall material response to impact and match that of the tissues we're interested in," he explains. Qing, 23, is a second-year PhD student and expects to finish his doctorate in 2018. He received his bachelor's degree at the University of California at Berkeley.

Stickiness challenge

Working with substitutes for extremely soft, or compliant, tissue like brain tissues poses some special challenges, Qing says. "When you are dealing with synthetic gels, once you reach a certain stiffness level, if you try to go below that, the gels just get very, very sticky, so it makes it very difficult to work with, especially for me, because I work with small volumes of material and analyze the response by physically contacting the gel surface," he says.

Principal investigator Van Vliet says it is more difficult to replicate soft tissue with engineered materials such as gels than to mimic hard tissue like bone with metal or ceramic substitutes. "As you get into these 'soft tissues,' like your heart, your brain, your liver, those are more complex to fabricate," she explains. "You're using polymers instead of metals and ceramics. There are a lot of parameters that one can tune, but usually those parameters are coupled with each other, so as the material gets less and less stiff, it also becomes increasingly sticky, for example. That's not always true in the tissues, but it's true for many of the engineered polymers."

"Bo is generating some of the first data on the brain tissue using this method, and then using the same approach to understand how polymers can be engineered to either match or protect the tissue," Van Vliet says. "We could make a very, very complicated material that looked just like brain tissue, had multiple layers to it, white and gray matter, but that's not really the point. The point is to make as simple a material as you can to mimic the mechanical behavior of interest so that you can then ultimately manufacture a lot of it at scale."

High impact rates

Qing, who has a National Defense Science and Engineering Graduate Fellowship, conducts impact tests on a nanoindenter on both rodent tissue and gel substitutes to establish parameters for accurate measurement. The experimental setup pushes a probe on a pendulum into the material at high impact rates. "What you get is displacement of the probe as a function of time, and from this output, we can analyze this data to get things like the material's resistance to penetration based on the maximum depth that the probe was able to penetrate into the material," Qing explains. "From these different bounces, we can analyze basically how much and how fast the impact energy is dissipated."

Each impact-indentation experiment takes approximately three seconds, though setup time is much longer. Impact load is measured in millinewtons. The tests are repeated at varying impact force and speed. "I've been characterizing these impact responses of all kinds of tissues and then designing synthetic gels that have the same impact response properties," Qing says.

"There's a lot of design space that nature has covered that we don't actually have access to right now," Van Vliet says. "But the community is learning through experiments like Bo's how to tune, for example, the stiffness of a material independently of how fast it can dissipate impact energy. There's a lot be learned in terms of how to mimic tissues and also how to keep it simple and inexpensive so that you can manufacture such materials at large scale."

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