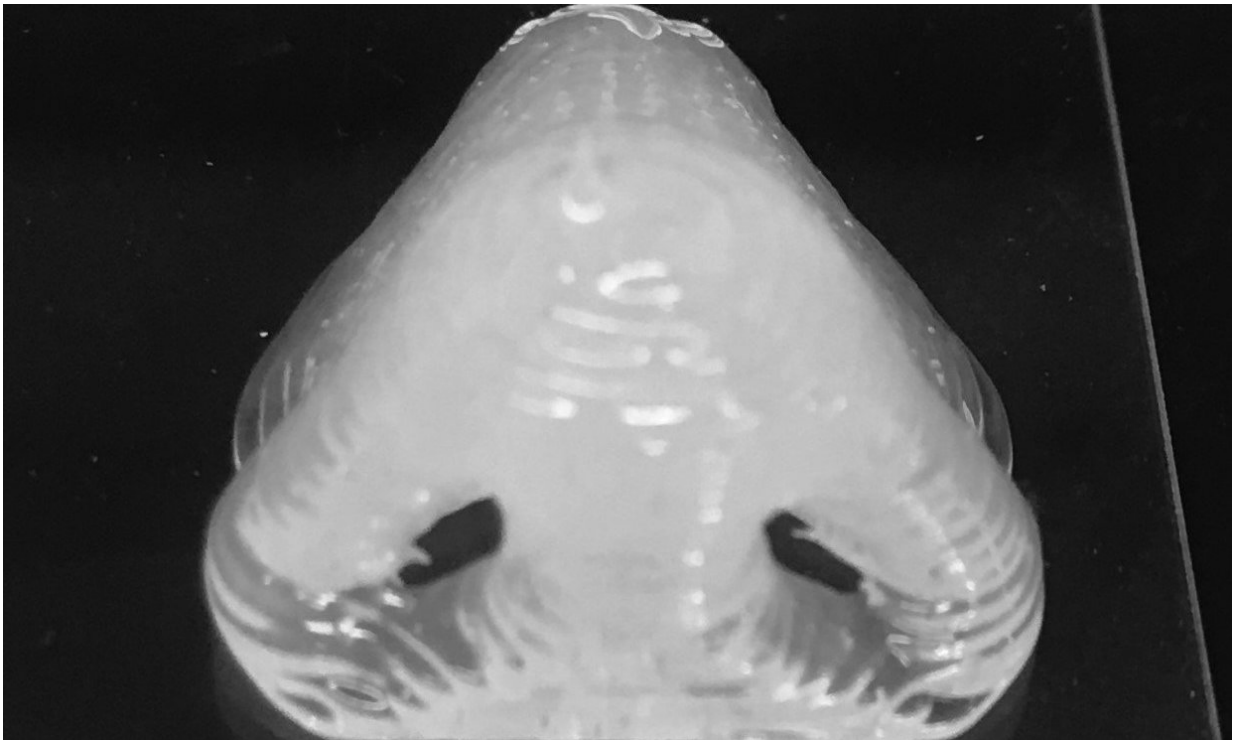


3-D printing improves cell adhesion and strength of PDMS polymer

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A nose created using 3-D printing of PDMS from National Institutes of Health 3-D Print Exchange. Credit: Ibrahim Tarik Ozbolat Lab / Penn State

Combining two different polymer forms can switch manufacturing of silicone parts from molding, casting and spin coating of simple forms to 3-D printing of complex geometries with better mechanical characteristics and better biological adhesion, according to a team of

Penn State researchers.

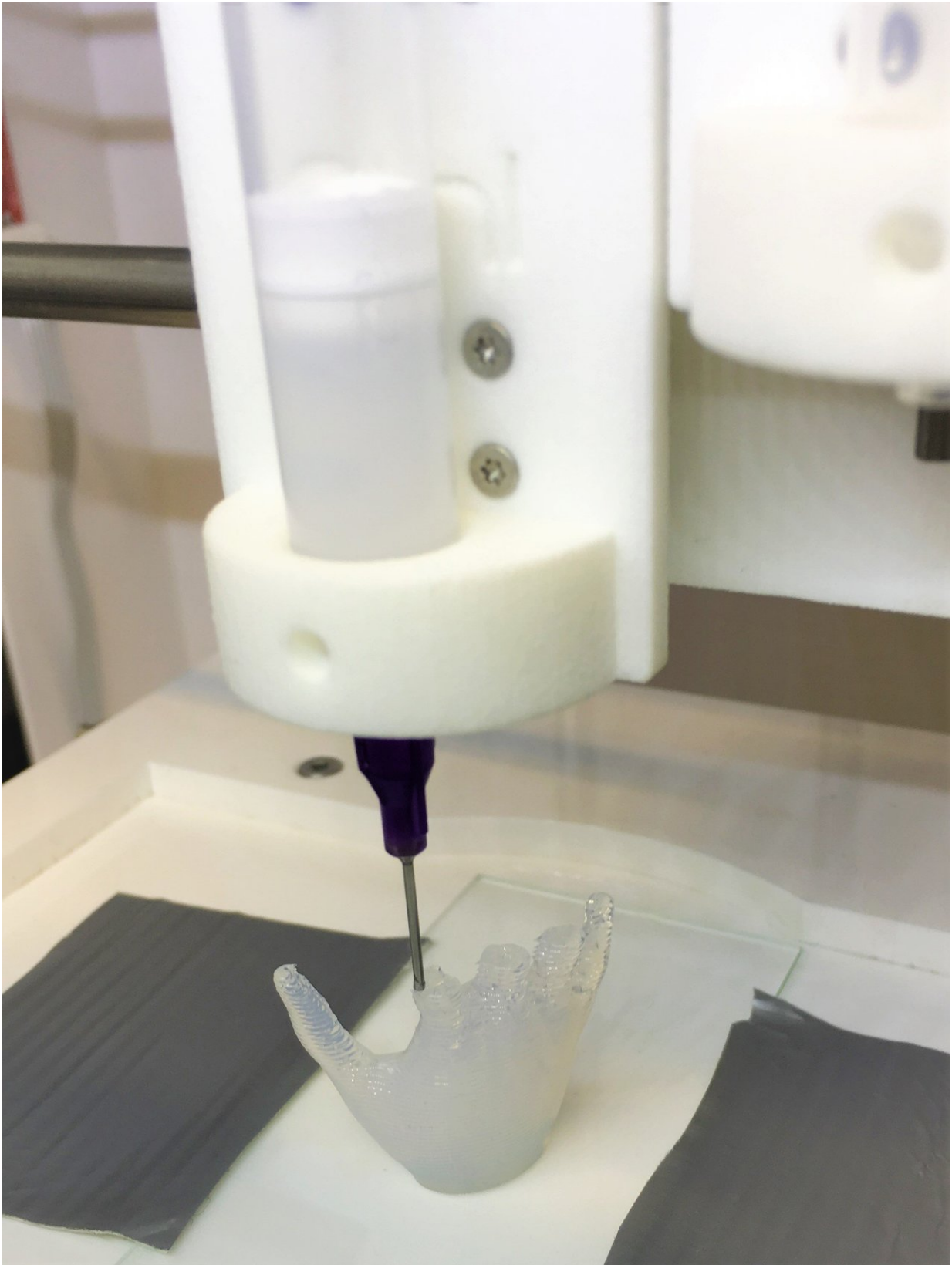
"So far, PDMS (polydimethylsiloxane, or silicone) has limitations in formability and manufacturing of devices," said Ibrahim T. Ozbolat, Hartz Family Associate Professor of Engineering Science and Mechanics and bioengineering. "Most research is done using casting or micro molding, but this fabrication yields [materials](#) with weak mechanical properties and also weak cell adhesion. Researchers often use extracellular proteins like fibronectin to make cells adhere."

PDMS is used to make lab-on-a-chip devices, organ-on-a-chip devices, two- and three-dimensional cell culture platforms, and biological machines. The material is more commonly seen as heat-resistant silicone spatulas and flexible baking pans, but these are geometrically simple and can easily be molded. If the material is used for growing tissue cultures or testing, the geometries become much smaller and more complex.

For any material to serve as "ink" in a 3-D printer, it must be able to go through the printing nozzle and maintain shape once it is deposited. The material cannot spread, seep or flatten or the integrity of the design is lost. Sylgard 184, an elastomer of PDMS, is not viscous enough to use in 3-D printing—the material simply flows out of the nozzle and puddles. However, when it is mixed with SE 1700, another PDMS elastomer, in the proper ratio, the mixture is printable.

"We optimized the mixture for printability, to control extrusion and fidelity to the original pattern being printed," said Ozbolat.

The researchers optimize the mixture to take advantage of a materials property called "shear thinning." They report their results in this month's issue of *ACS Biomaterials Science & Engineering*.



3-D printer printing a hand from PDMS. Credit: Ibrahim Tarik Ozbolat Lab / Penn State

While most materials become more viscose under pressure, some materials have the opposite, non-Newtonian response, becoming less viscose. This is perfect for 3-D printing because a fluid that is viscose enough to sit in the nozzle then becomes less viscose when the pressure of pushing out the "ink" occurs. As soon as the material leaves the nozzle, it regains its viscosity and the fine threads placed on the object retain their shape.

PDMS, when molded, has a smooth surface. The material is also hydrophobic, meaning it does not like water. Add those two properties together and the molded surface of PDMS is not an easy place for tissue cells to adhere. Researchers frequently use coatings to increase cell adherence. 3-D-printed surfaces, because they are made up of thousands of tiny strands of PDMS, have minute crevices that offer cells a place to stick.

To test the fidelity of 3-D printing with PDMS, the researchers obtained patterns for biological features—hands, noses, blood vessels, ears, and femoral head, from the National Institutes of Health 3-D Print Exchange. Using these patterns they 3-D printed a nose. Organs like this can be printed without support materials and include hollow cavities and complex geometries.

"We coated the PDMS nose with water and imaged it in an MRI machine," said Ozbolat. "We compared the 3-D reconstructed nose image to the original pattern and found that we had pretty decent shape fidelity."

Because PDMS is forced through a nozzle for printing, the number of bubbles in the final material is far less than with molding or casting. Passing through a micrometer size needle removes most of the bubbles.

"When we compared the mechanical signatures of molded or cast PDMS with 3-D printed PDMS, we found the tensile strength in the printed material was much better," said Ozbolat.

Because the PDMS materials are being printed, they could be incorporated with other materials to make one-piece devices composed of multiple materials. They could also incorporate conductive materials to enable functionalized devices.

Provided by Pennsylvania State University

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