An origami-inspired medical patch for sealing internal injuries

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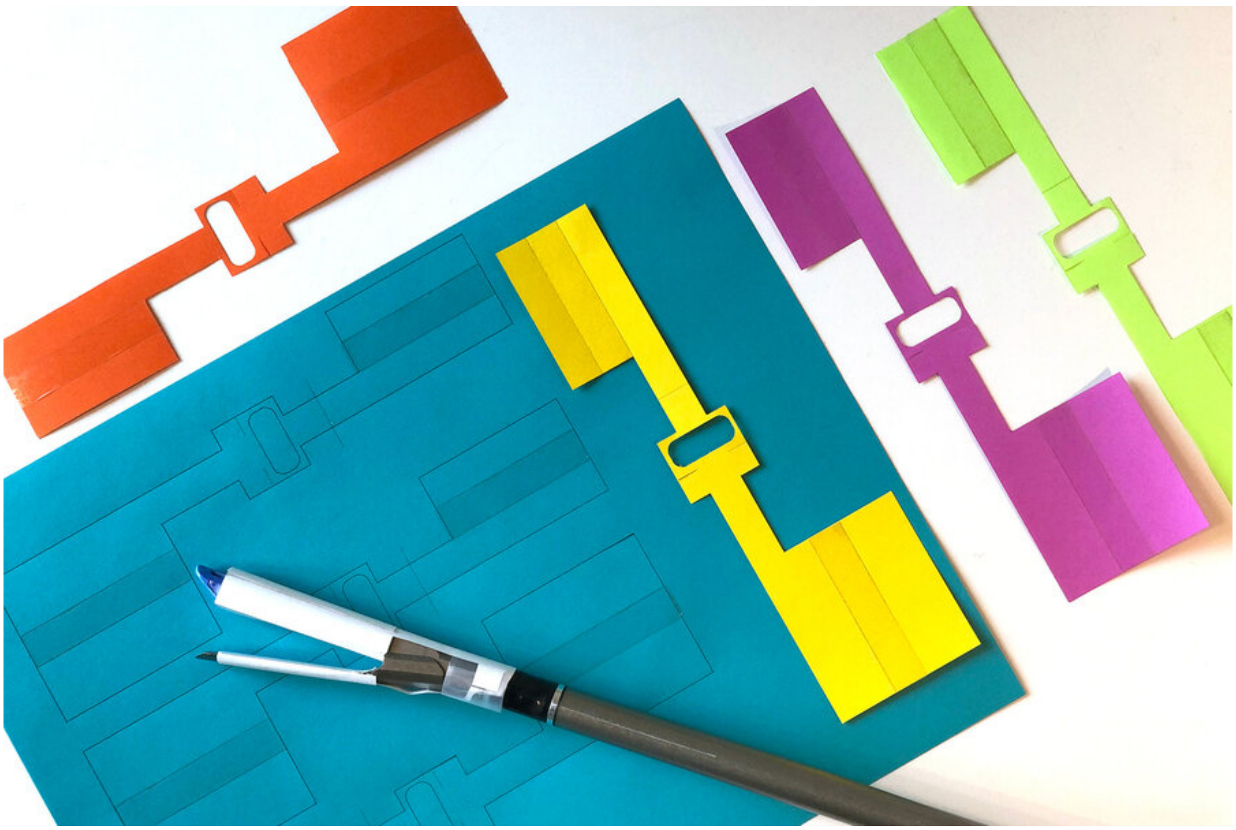

MIT engineers have design paper-like medical tapes (shown here) that can fold around surgical tools and transform into soft, strong adhesives when pressed against tissues. Credit: Felice Frankel

Many surgeries today are performed via minimally invasive procedures, in which a small incision is made and miniature cameras and surgical tools are threaded through the body to remove tumors and repair damaged tissues and organs. The process results in less pain and shorter recovery times compared to open surgery.

While many procedures can be performed in this way, surgeons can face challenges at an important step in the process: the sealing of internal wounds and tears.

Taking inspiration from origami, MIT engineers have now designed a medical patch that can be folded around minimally invasive surgical tools and delivered through airways, intestines, and other narrow spaces, to patch up internal injuries. The patch resembles a foldable, paper-like film when dry. Once it makes contact with wet tissues or organs, it transforms into a stretchy gel, similar to a contact lens, and can stick to an injured site.

In contrast to existing surgical adhesives, the team's new tape is designed to resist contamination when exposed to bacteria and bodily fluids. Over time, the patch can safely biodegrade away. The team has published its results in the journal *Advanced Materials*.

The researchers are working with clinicians and surgeons to optimize the design for surgical use, and they envision that the new bioadhesive could be delivered via minimally invasive surgical tools, operated by a surgeon either directly or remotely via a medical robot.

"Minimally invasive surgery and robotic surgery are being increasingly adopted, as they decrease trauma and hasten recovery related to open surgery. However, the sealing of internal wounds is challenging in these surgeries," says Xuanhe Zhao, professor of mechanical engineering and of civil and environmental engineering at MIT.

"This patch technology spans many fields," adds co-author Christoph Nabzdyk, a cardiac anesthesiologist and critical care physician at the Mayo Clinic in Rochester, Minnesota. "This could be used to repair a perforation from a coloscopy, or seal solid organs or blood vessels after a trauma or elective surgical intervention. Instead of having to carry out a full open surgical approach, one could go from the inside to deliver a patch to seal a wound at least temporarily and maybe even long-term."

The study's co-authors include lead authors Sarah Wu and Hyunwoo Yuk, and Jingjing Wu at MIT.

Layered protection

The bioadhesives currently used in minimally invasive surgeries are available mostly as biodegradable liquids and glues that can be spread over damaged tissues. When these glues solidify, however, they can stiffen over the softer underlying surface, creating an imperfect seal. Blood and other biological fluids can also contaminate glues, preventing successful adhesion to the injured site. Glues can also wash away before an injury has fully healed, and, after application, they can also cause inflammation and scar tissue formation.

The new origami-inspired medical patch can be folded over tools like surgical staplers (shown here) and threaded through the body to suture tissues and organs. Credit: Massachusetts Institute of Technology

Given the limitations of current designs, the team aimed to engineer an alternative that would meet three functional requirements. It should be able to stick to the wet surface of an injured site, avoid binding to anything before reaching its destination, and once applied to an injured site resist bacterial contamination and excessive inflammation.

The team's design meets all three requirements, in the form of a three-layered patch. The middle layer is the main bioadhesive, made from a hydrogel material that is embedded with compounds called NHS esters. When in contact with a wet surface, the adhesive absorbs any surrounding water and becomes pliable and stretchy, molding to a tissue's contours. Simultaneously, the esters in the adhesive form strong covalent bonds with compounds on the tissue surface, creating a tight seal between the two materials. The design of this middle layer is based on previous work in Zhao's group.

The team then sandwiched the adhesive with two layers, each with a different protective effect. The bottom layer is made from a material coated with silicone oil, which acts to temporarily lubricate the adhesive, preventing it from sticking to other surfaces as it travels through the body. When the adhesive reaches its destination and is pressed lightly against an injured tissue, the silicone oil is squeezed out, allowing the adhesive to bind to the tissue.

The adhesive's top layer consists of an elastomer film embedded with zwitterionic polymers, or molecular chains made from both positive and negative ions that act to attract any surrounding water molecules to the elastomer's surface. In this way, the adhesive's outward-facing layer forms a water-based skin, or barrier against bacteria and other contaminants.

"In minimally invasive surgery, you don't have the luxury of easily accessing a site to apply an adhesive," Yuk says. "You really are battling a lot of random contaminants and body fluids on your way to your destination."

Fit for robots

In a series of demonstrations, the researchers showed that the new bioadhesive strongly adheres to animal tissue samples, even after being submerged in beakers of fluid, including blood, for long periods of time.

They also used origami-inspired techniques to fold the adhesive around instruments commonly used in minimally invasive surgeries, such as a balloon catheter and a surgical stapler. They threaded these tools through animal models of major airways and vessels, including the trachea, esophagus, aorta, and intestines. By inflating the balloon catheter or applying light pressure to the stapler, they were able to stick the patch onto torn tissues and organs, and found no signs of contamination on or near the patched-up site up to one month after its application.

The researchers envision that the new bioadhesive could be manufactured in prefolded configurations that surgeons can easily fit around minimally invasive instruments as well as on tools that are currently being used in robotic surgery. They are seeking to collaborate with designers to integrate the bioadhesive into robotic surgery platforms.

"We believe that the conceptual novelty in the form and function of this patch represents an exciting step toward overcoming translational barriers in robotic surgery and facilitating the wider clinical adoption of bioadhesive materials," Wu says.

More information: Sarah J. Wu et al. A Multifunctional Origami Patch for Minimally Invasive Tissue Sealing, *Advanced Materials* (2021). DOI: 10.1002/adma.202007667

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