I BET YOU DIDN'T KNOW...

Slug slime might be the answer for medical adhesives

Dr Paul Tyler, PSTT College Fellow, links **cutting edge research** with the **principles of primary science**

paul.tyler@pstt.org.uk

Ever had a plaster come off in the swimming pool? Experienced the frustration of something not sticking to a wet surface? You're not alone – it's a problem that has kept scientists busy for years.

Water is one of the most effective barriers to sticking two surfaces together. It forms a physical barrier that prevents the adhesive making a good contact with the surface. Materials scientists, chemists and engineers have been looking for solutions ever since the first synthetic adhesives were developed.

In the classroom, we can ask the children: What uses can you think of for adhesives? Is the same adhesive suitable for all situations? Children can easily make their own simple glues (e.g. from flour and water; milk, vinegar and baking soda; syrup and cornflour) and investigate which mixtures are effective for sticking paper or other materials together.

A brief history of adhesion

Archaeologists have discovered evidence that adhesives have been used for thousands of years. Cave dwellers used bitumen to stick sharp flints to their wooden spears. People then discovered that resin from pine trees and boiling animal bones made effective adhesives for a variety of uses. Nowadays, most adhesives we use are man-made from a variety of synthetic chemicals.

Adhesives come in a wide range of forms and have an almost infinite number of applications. From leaving notes for people to making models, sealing parcels to laying bricks, DIY tasks to industrial repairs, covering cuts and grazes to sealing major organs after surgery, the right adhesive can stick pretty much anything.

Adhesives in Medicine

There are many uses for adhesives that can stick to biological material, including internal tissue repair, drug delivery, wound dressings and fixing biomedical devices. Manufacturers of adhesives for medical use have a set of unique challenges that have led scientists to look to the natural world and explore some novel solutions.

Biological adhesives need to:

- be able to stick to wet surfaces
- adhere strongly to human tissue
- be flexible once cured
- be non-toxic (they can't contain cytotoxic chemicals)

Many of the current adhesives available are unsuitable in a lot of situations.

Cyanoacrylate (Super Glue) is the strongest tissue adhesive but it is cytotoxic, doesn't work on wet surfaces and is very rigid when it is cured.

Nanoparticle and mussel-inspired adhesives don't stick well to wet biological tissue.

Fibrin glues and polyethylene glycol-based adhesives are too rigid when cured and become brittle.

Biomimicry

Human innovation is often inspired by what we see in the natural world around us (Figure 1). Ask the children**: Can you think of any animals that might use adhesives? Do any of these use their adhesives in wet conditions? Can you think of anything you use regularly that might have been inspired by something in nature?**

Figure 1. Examples of human innovation inspired by nature.

The nose of the Shinkansen Bullet Train is modelled on the beak of a kingfisher which can dive into water with barely a splash.

Wind turbine efficiency is being improved by mimicking the tubercles from the flippers of humpback whales.

The hook and loop fastening system, one of the first biomimicry examples, is based on the tiny hooks on cocklebururs that cause them to attach tightly to clothing and fur.

Researchers in Japan have engineered a needle, based on the moving parts of a mosquito's mouth, that penetrates the skin painlessly.

For years, scientists have studied the strong adhesive used by mussels and being able to mimic it for use in wet conditions; it even cures underwater. However, it is too rigid, when cured, to be used in medical applications. A group of scientists from around the world have being collaborating on a study of slugs (*Arion subfuscus*), and specifically the mucus they secrete to defend themselves (Figure 2). This mucus adheres very strongly to wet surfaces.

Figure 2. A new family of tough adhesives, with medical applications, has been inspired by slug slime. A species of land slug, Arion subfuscus, commonly found across Europe and Asia, secretes a defensive mucus that strongly adheres to wet surfaces. ©Erik Veldhuis licenced through Creative Commons and accessed here.

Inspired by the chemical properties of the slug mucus, the scientists have synthesised a family of Tough Adhesives (TAs) that adhere very strongly to wet surfaces, including biological tissue. They also have incredible flexibility, being able to stretch up to 14 times their initial length. Most importantly they are non-toxic to human cells. The TAs synthesised can be applied as a patch or injected as a liquid making them highly flexible and able to be used in several medical applications.

Glossary

Adhesive	Glue; substance that sticks two surfaces together
Biomimicry	Using natures' strategies to develop solutions to human problems
Cytotoxin	A chemical that kills living cells.
Nanoparticle	Tiny particle, less than 100 nanometres in size (a nanometre is 1 billionth of a metre)
Cure	To set, or go hard
Synthesised	Made, usually in a laboratory

The research paper that generated this work was:

Tough adhesives for diverse wet surfaces

By J. Li,[1,2,3] A. D. Celiz,[2,4*†] J. Yang,[1,5*] Q. Yang,[1,5,6] I. Wamala,[7] W. Whyte,[1,2,8] B. R. Seo,[1,2] N. V. Vasilyev,[7] J. J. Vlassak,[1] Z. Suo,[1,5] and D. J. Mooney.[1,2‡]

Science **357**, 378-381 (2017)

1 John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA. 2 Wyss Institute for Biologically Inspired Engineering, Harvard University, Cambridge, MA 02138, USA.
3Department of Mechanical Engineering, McGill University, Montreal, Quebec H3A 0G4, Canada.
4 Advanced Materials and Healthcare Technologies Division, School of Pharmacy, University of Nottingham, Nottingham NG7 2RD, UK.
5 Kavli Institute for Nanobio Science and Technology, Harvard University, Cambridge, MA 02138, USA.
6 School of Aerospace, Tsinghua University, Beijing 100084, People's Republic of China.
7 Departments of Cardiac Surgery, Boston Children's Hospital, Boston, MA 02115, USA.
8 Advanced Materials and Bioengineering Research Centre, Royal College of Surgeons in Ireland and Trinity College Dublin, Dublin, Ireland.
*These authors contributed equally to this work.
†Present address: Department of Bioengineering, Imperial College London, London SW7 2AZ, UK.
‡Corresponding author. Email: mooneyd@seas.harvard.edu