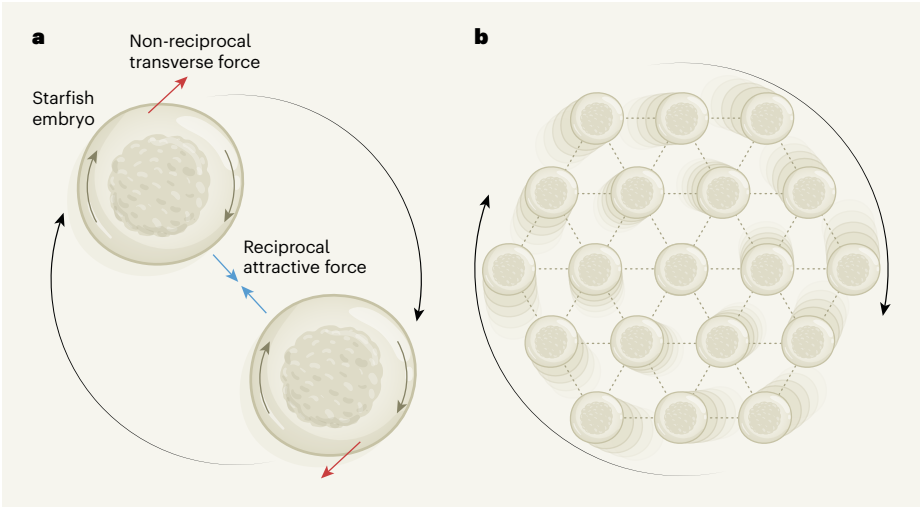

Figure 1 | Non-reciprocal interactions between starfish embryos. a, Tan *et al.*[1] report the formation of a crystal in which the 'atoms' are starfish embryos floating on water, which spin around their own axis. Hydrodynamic interactions between two spinning embryos give rise to a reciprocal attractive force (blue arrows), but also a non-reciprocal transverse force (red arrows), which causes spontaneous rotation of the embryos around one another. **b**, The attractive forces cause many of these embryos to cluster into a crystal. This cluster spins as a whole. The microscopic transverse forces give this crystal an 'odd' elastic response, which is forbidden by classical mechanics.

from which they came. For example, an active nematic framework gave rise to the revelation that defects in nematic ordering can help to coordinate the development of organisms[7].

In the same vein, Tan and colleagues' identification of odd elasticity in a biological system invites two broader questions. First, how widespread are odd behaviours in living matter? Second, do they serve some biological function? The team's experiments demonstrate the fundamental link between oddness and chirality (handedness): odd elasticity necessarily implies that a material can be distinguished as being either right-handed or left-handed. In Tan and co-workers' experiments, chirality dictates the direction of rotation of the starfish embryos. More generally, chirality is found in many biological systems, so the findings hint at the idea that odd behaviour might also be commonplace. Could it imply a role for chirality that hasn't yet been revealed?

Seen instead from a design perspective, the platform that Tan *et al.* have developed is a step along the road to animate matter[9] – materials that are able to sense, compute and respond to an external stimulus. Such materials might mimic animate behaviour by synthetic means[10], as in the realization of odd elasticity in a system of spinning colloids, reported this year[11]. Alternatively, they might directly include biological elements, as is the case in the starfish-embryo crystals. This latter approach has the advantage that an internal energy reservoir is built into the system: the odd elasticity demonstrated by Tan *et al.* lasts for several hours without external input, stopping only when embryo growth breaks the crystal apart.

In what sense is an odd material animate? Tan and colleagues' system generates spontaneous waves of oscillations in the positions of the embryos, and these waves persist throughout the lifetime of the crystal. A theoretical prediction for odd materials is that such waves can be induced in response to external compression – or, more generally, that a system displaying odd behaviour will exhibit oscillatory motion in response to specific stimuli. Such dynamical states could form the basis of mechanical programming and computation in the material itself; for example, by switching between different dynamical states in response to different stimuli.

Tan and co-workers' study sits at the nexus of materials design and fundamental physics: their system gives us a glimpse into how breaking the golden rule of reciprocity leads to intriguing emergent behaviour in active solids. Although odd elasticity is one hallmark of living crystals, there are likely to be many others. We are yet to understand the broader principles of designer materials created using living constituents.

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Virology

Norovirus from the mouths of babes

Elizabeth A. Kennedy & Megan T. Baldridge

The discovery that gut viruses can be transmitted from mouse pups to their mothers in saliva during breastfeeding reveals previously unrecognized sites of viral replication and means of viral transmission. **See p.345**

Gastrointestinal viruses such as norovirus and rotavirus spread with impressive efficiency, causing more than 300 million childhood infections worldwide each year[1]. These viruses can cause a range of unpleasant symptoms, including abdominal pain, diarrhoea and vomiting. They are thought to be spread almost exclusively through the faecal–oral route, in which a person ingests tiny particles of stool or vomit that have either come directly from an infected person or have contaminated food and water. But on page 345, Ghosh *et al.*[2] present intriguing evidence of salivary infection routes for gastrointestinal viruses, indicating that measures to contain viral spread might require enhanced sanitation techniques.

It has been assumed that, once ingested, gastrointestinal viruses replicate mainly in intestinal cells before being shed in the stool, thereby driving the next cycle of transmission[3]. Although viral copies have been detected in the saliva of infected people even in the absence of vomiting, these particles were thought to be a

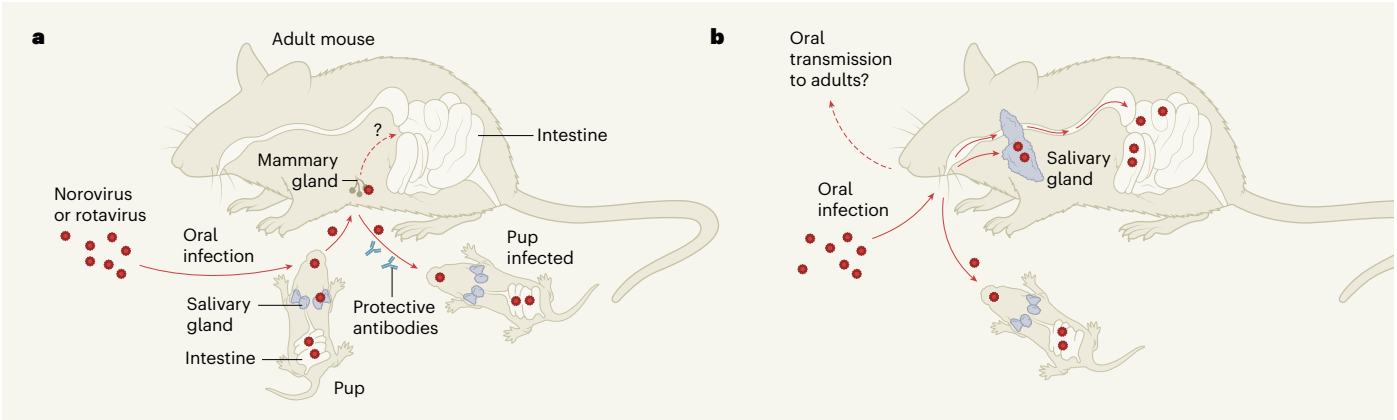

Figure 1 | Unexpected routes for transmission of gastrointestinal viruses. Ghosh *et al.*[2] describe previously unknown routes by which noroviruses and rotaviruses are transmitted in mice. **a**, Mouse pups orally inoculated with these viruses exhibit infection both in their intestines and in their salivary glands. They can pass virus to their mothers during breastfeeding, who can in turn pass both virus and protective antibodies back to pups. Whether infection of the mammary gland leads to intestinal infection in the mother is unclear. **b**, Adult mice orally inoculated with virus also develop both intestinal and salivary gland infection, and can pass the virus to pups through saliva. Whether these viruses can be transmitted between adults in saliva is unknown.

by-product of gut infection[4,5]. For that reason, saliva has not typically been considered a transmission route[3].

Ghosh *et al.* began to question this assumption when they observed that mouse pups infected with norovirus or rotavirus could transmit infection to the mammary glands of their mothers by suckling breast milk. This mammary-gland infection stimulated an increase in protective antibodies, which were then released in breast milk (Fig. 1a).

The authors confirmed that viruses could be detected in the salivary glands of pups for at least as long as the virus was present in the pups' intestines. Antibodies in breast milk can passively protect suckling neonates from infections, including those caused by diarrhoeal pathogens[6]. Perhaps oral transmission of gastrointestinal viruses from pup to mother signals a need for further protection in young infected animals, which have not yet fully developed their own immune systems. It remains to be tested whether these antibodies help to clear viral infection in suckling pups. The authors also showed that mothers infected by suckling pups could then pass the virus to uninfected pups in their breast milk, indicating that the virus can pass both ways.

Ghosh *et al.* also assessed whether adult mice infected through the previously documented oral route can release infectious virus in saliva. They found that adult salivary glands can indeed be infected by some strains of norovirus and rotavirus, and that saliva from infected adults can be used to orally transmit infection to pups (Fig. 1b). However, not all viral strains could infect the salivary glands. This mirrors findings in humans, because not all norovirus strains that can infect the human intestines can be detected in saliva[5]. Thus, oral transmission is likely to be possible for some, but not all, gastrointestinal viruses. It remains to be determined what characteristics govern the capacity of a virus to infect the salivary gland.

A major challenge in human norovirus research has been establishing methods to grow the virus easily and robustly in the laboratory: 3D cultures of human intestinal cells, dubbed mini-guts, have been developed to cultivate human noroviruses[7], but working with them can be costly and challenging. Excitingly, Ghosh *et al.* found that mouse and human noroviruses could be cultivated in mouse 'mini salivary glands' or in cell lines derived from human salivary glands, respectively. These systems could be a good alternative to mini-guts, making it easy to study how human norovirus and other gastrointestinal viruses replicate, and thereby aiding the development and testing of antiviral treatments and vaccines.

Ghosh and colleagues' work opens several areas of future research. Perhaps the most pressing is to determine how relevant these findings are to human viral transmission. Although genetic material from gut viruses has been detected in human saliva[4,5], it remains unclear whether this material comes from still-infectious viruses, which would enable oral-to-oral transmission of infection. If salivary infection does occur in humans, do mammary-gland infection and antibody transfer also play out in the same way, helping breastfeeding infants to clear dangerous viral infections of the gut?

"The study points to the salivary gland as a new therapeutic target, perhaps targetable by methods such as antiviral mouthwashes."

How broadly relevant are oral-to-oral transmission dynamics to other viruses that can infect the intestine, such as enteroviruses and adenoviruses? Can we now study these in the same salivary-gland model systems? Finally, a great deal of research has already clarified the host and immune factors that mediate viral infections in the gut. Future work should investigate whether the same immune pressures govern infection in the salivary glands, or whether there are distinct host–virus interactions in this alternative niche.

Although typically short-lived in healthy adults, gastrointestinal viral infections are a leading global cause of child mortality, leading to about 200,000 deaths annually[1]. Prevention of virus transmission has focused mainly on blocking faecal–oral routes of infection, but Ghosh *et al.* raise the possibility that these viruses can also spread in a community through saliva. Using masks to limit the conversion of salivary droplets into aerosols, and avoiding saliva-sharing practices, such as kissing or sharing utensils and cups, are enhanced sanitary practices that could be evaluated to minimize transmission. In addition, the study points to the salivary gland as a new therapeutic target, perhaps targetable by methods such as antiviral mouthwashes, to disrupt transmission or reduce the severity of infection.

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