charge stays constant and the upward renormalization of α_G is due to a decreasing Fermi velocity at increasing energies. In both QED and graphene, the renormalization of the coupling between two different energies E_1 and E_2 is given by the relation

$$\alpha(E_2)=\frac{\alpha(E_1)}{1-A\alpha(E_1)\ln(E_2/E_1)}$$

where A is a constant that depends on the number of fermion species that contribute to the renormalization at energy E_2.

The idea that such a renormalization would occur in graphene was suggested almost a decade before it had actually been successfully isolated[3]. The reason it has taken so long since graphene's initial isolation to confirm it experimentally is that it only becomes evident within 1 eV of the Dirac point and a clear demonstration of the validity of any logarithmic relation naturally requires a dataset that spans several orders of magnitude. In this sense, the experiments performed by Elias *et al.* represent a real tour-de-force, probing graphene's electronic structure down to fractions of meV of the Dirac point, and confirming the logarithmic behaviour all the way down to this point. Beyond establishing the QED-like behaviour of graphene further than any physicist might have reasonably expected, the result improves our understanding of the often controversial nature of electron–electron interactions in neutral graphene.

Maria A. H. Vozmediano is at the Instituto de Ciencia de Materiales de Madrid (CSIC), Sor Juana Inés de la Cruz 3, Madrid 28049, Spain.
e-mail: vozmediano@icmm.csic.es

References
1. Novoselov, K. S. *et al. Nature* **438,** 197–200 (2005).
2. Elias, D. C. *et al. Nature Phys.* **7,** 701–704 (2011).
3. González, J., Guinea, F. & Vozmediano, M. A. H. *Nucl. Phys. B* **424,** 595–618 (1994).

Published online: 24 July 2011

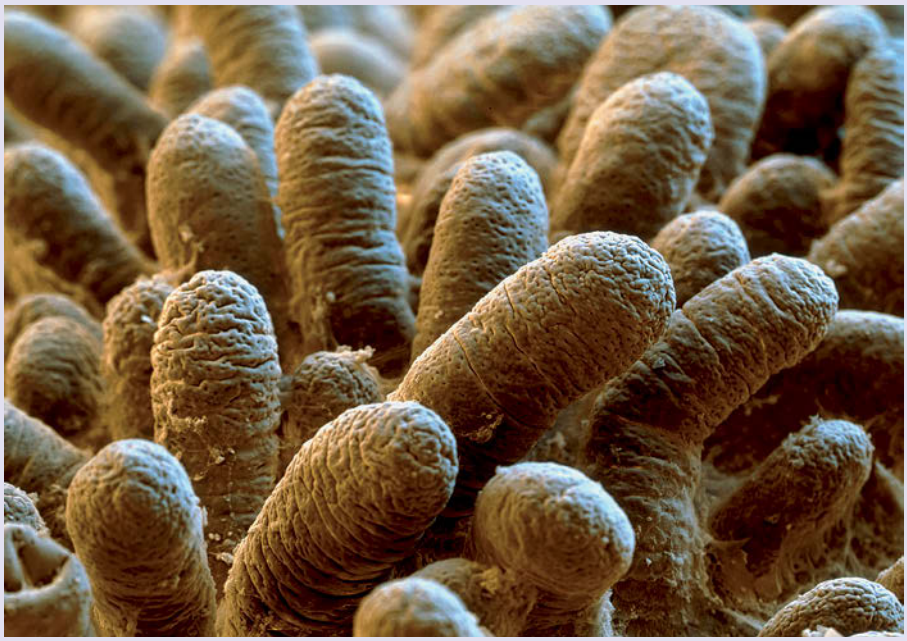
BIOPHYSICS

On mechanics and morphology

When D'Arcy Thompson penned his 1917 book *On Growth and Form* he boldly declared that the morphologist — devoted to understanding the structure of organisms — is *ipso facto* a student of physical science. His meaning was clear: the growth of complex structures mediating specific biological function is underpinned by an intrinsic mechanics, an appreciation of which is crucial to a broader understanding of both form and function.

Thierry Savin and colleagues refer to Thompson's tome in their investigation, published in *Nature*, of the elaborate looped morphology that arises in the vertebrate gut (*Nature* **476,** 57–62; 2011). Using experiment, simulation, and an innovative physical mock-up comprising rubber tubing stitched to latex, they have examined the forces arising from relative growth between the gut tube and a neighbouring sheet of tissue known as the dorsal mesentery. The study reveals a mechanism for the formation of loops based on differential strain between the two tissues.

This is a timely nod to Thompson's century-old ideas, given the recent surge of physicists and mathematicians into the biological sciences, problem-solving artillery engaged. In another paper, published in *Physical Review Letters*, Edouard Hannezo, Jacques Prost and Jean-François Joanny adopt a similarly mechanical approach to understanding the complex structures seen lining the small intestine (pictured), invoking an analogy with the buckling of metallic plates under compression (*Phys. Rev. Lett.* **107,** 078104; 2011). They have developed a model that implicates cellular division and death as sources of internal stress, which in turn influences morphology and induces mechanical feedback on organ and tissue development.



© SPL

One of the most interesting aspects of Thompson's treatise is an emphasis on the degree to which structures in different tissues and organisms can be related to one another by means of mathematical transformation. Both of the new papers offer striking evidence to this effect. For Savin *et al.*, scaling arguments for the size, number and radius of loops account for qualitative and quantitative variation across different species, including chick, quail, finch and mouse. In a similar spirit, Hannezo and colleagues report that by tuning their model for the morphology of the small intestine, the markedly different structures populating the colon can also be reproduced.

The upshot of this and related work is that macroscopic mechanics drives morphology during the formation of tissues and organisms — bringing the formalism of physics to bear on long-standing problems in developmental biology.

ABIGAIL KLOPPER

Nature Reviews Gastroenterology & Hepatology **8**, 533 (2011); doi:10.1038/nrgastro.2011.143

DEVELOPMENT

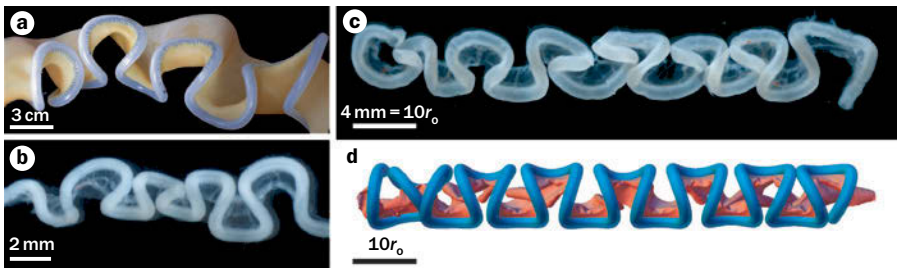
Predictable looping of the developing vertebrate gut explained

An interdisciplinary team of researchers from Harvard has shed light on why the developing vertebrate gut tube loops in a predictable way that is conserved within a given species, giving credence to the mathematical and physical approach to biological shape that was championed by D'Arcy Thompson in his 1917 book *On Growth and Form*. Using developmental experiments, a physical mimic, a mathematical theory and a computational model, they have shown that it is differences in the growth rate of the gut tube and the dorsal mesentery that forces the gut tube to coil.

"When Cliff Tabin and Natasza Kurpios showed me images of the gut, I hypothesized that differential growth between the gut and mesentery was responsible for the pattern and was able to construct a theory for the size and shape of the loops," explains L. Mahadevan, corresponding author. "One might think that the gut coils because it is restricted by the size of the abdominal cavity. That's not actually the case," says coauthor Thierry Savin. "The gut coils because when the mesentery and the gut tube grow at different rates while remaining attached, coiling is the only possible result."

Developmental experiments excluded the possibility that external spatial packing constraints were responsible for the predictable looping. When the gut tube and dorsal mesentery were surgically dissected from chick embryos, not only did the loops remain in place but their structure was also identical to that seen *in ovo* at multiple developmental stages. The idea that asymmetrical proliferation of cells present in the bends of the gut tube could be responsible for the looping was also ruled out, as the number of mitotic cells present was consistent across the gut independent of developmental stage.

The role of the dorsal mesentery, which attaches the gut tube to the body, was investigated by separating the chick dorsal mesentery from the gut tube at embryonic day 14 (E14). After separation, the gut tube uncoiled into a straight tube, whereas the dorsal mesentery contracted, suggesting the gut tube was being compressed and the dorsal mesentery was under tension. Surgical separation of part of the dorsal mesentery from the gut *in ovo* at E4, prior to gut loop development, revealed an absence of gut loops in only those regions of the E12 chick gut in which the mesentery and gut had been separated.



The structure of the relaxed physical model (a) is very similar to the structure of the chick gut (b) shown at embryonic day 12 (E12). The chick gut at E16 (c) and its simulated counterpart (d). © Savin, T. *et al. Nature* **476**, 57–62 (2011).

As the dorsal mesentery was then shown to grow uniformly, as does the gut tube, it confirmed to the team "…that the uniform differential growth between the gut and the mesentery could be at the origin of loop formation. Because the gut tube is slender, with a length that is much larger than its radius, it responds physically to the differential strain-induced compression from the attached mesentery by bending and looping…"

This naturally suggested a physical model of the looping in terms of a latex sheet (mesentery) and a silicone tube (gut tube). The latex sheet was stretched along the length of unstretched silicone tube and the two stitched together. Using the model, it was possible to simulate the differential strain placed on the gut tube and dorsal mesentery by their differential growth. When the composite was allowed to relax, the silicone tube looped in a very similar way to the *in ovo* chick gut.

Bolstered by this and armed with mathematical scaling laws for the loop period, radius and number, the team generated predictions for gut looping at different stages of chick development in terms of the measurable geometry, elasticity and strain mismatch. The data also allowed for detailed numerical simulation of gut looping. "Our model captures the salient properties of the looping patterns … strongly suggesting that the main features of the chick gut looping are established by the simple balance of forces induced by the relative growth between the gut and the mesentery," say the authors.

Finally, the researchers tested their computational model in other species—quail, zebra finch and mice. They confirmed the accuracy of the predictions with geometrical and biophysical data collected from these species. "A simple mathematical scaling theory combined with computations showed that these patterns are quantitatively predictable using experimentally derived measurements with no adjustable parameters. This allows for a study of the pattern as a function of developmental time—and even across species," concludes Mahadevan.

Natalie J. Wood

Original article Savin, T. *et al.* On the growth and form of the gut. *Nature* **476**, 57–62 (2011)

IN BRIEF

DEVELOPMENT

Notch and Ras promote sequential steps of excretory tube development in *C. elegans*

Abdus-Saboor, I. *Development* **138**, 3545–3555 (2011)

The excretory organ in *Caenorhabditis elegans* is made up of three stacked unicellular tubes — an excretory canal cell, a duct and a G1 pore, the second two of which arise from one of two equivalent progenitor cells. Abdus-Saboor *et al.* now show that LET-60 (RAS in mammals) promotes duct over G1 pore identity, as well as the stacking of the duct and G1 pore next to the canal cell, through the canonical LIN-3–LET-60–mitogen-activated protein kinase 1 pathway. The canal cell, which they found to express LIN-3 (epidermal growth factor in mammals), is required for duct and G1 pore stacking, as its removal (by inhibition of Notch signalling) disrupted this. So, Notch signalling promotes the formation of LIN-3-expressing canal cells, and LIN-3 activates LET-60 signalling in one progenitor cell to promote duct formation.

EPIGENETICS

Jarid2 regulates mouse epidermal stem cell activation and differentiation

Mejetta, S. *et al. EMBO J.* 2 Aug 2011 (doi:10.1038/emboj.2011.265)

In embryonic stem cells, JARID2 (jumonji and ARID domain-containing 2) is required for the recruitment of polycomb repressive complex 2 (PRC2), which catalyses histone H3 Lys27 trimethylation (H3K27me3); however, the role of JARID2 in late development and adult tissues was not well understood. Mejetta *et al.* conditionally deleted JARID2 in mouse epidermis and found that it is involved in maintaining robust proliferation of hair follicles during the postnatal anagen (growth) phase. JARID2 was dispensable for embryonic epidermal development but was important postnatally, as loss of JARID2 reduced proliferation and enhanced differentiation of postnatal epidermal progenitor cells. Consistent with JARID2's function in recruiting PRC2, there was a mild reduction in global H3K27me3 and reduced H3K27me3 at known PRC2 target genes in JARID2-knockout neonatal epidermis. The authors propose that JARID2 functions to maintain normal epidermal homeostasis and is required for efficient postnatal activation of hair follicle stem cells.

DEVELOPMENT

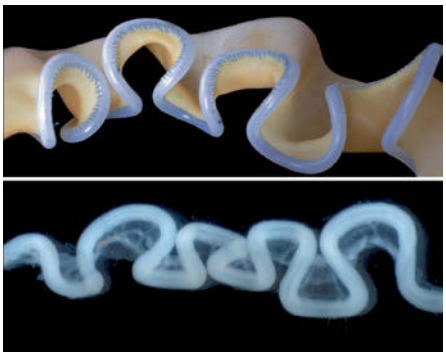
On the growth and form of the gut

Savin, T. *et al. Nature* **476**, 57–62 (2011)

Savin *et al.* studied the looping morphogenesis of the gut in vertebrates as an example of the role of mechanical forces in organogenesis. The gut starts as a linear tube and forms a looped pattern as it develops in the body cavity. By carrying out surgical experiments, the authors showed that loop formation results from tissues growing at different rates — there is uniform differential growth between the gut tube and the anchoring dorsal mesentery (a structure of mesodermal origin that is important for gut development and the normal function of the adult digestive system). The authors then simulated the formation of the loop pattern using a simple physical model based on a rubber tube and a thin latex tube. This system was used to develop a computational model that predicts the number, size and shape of intestinal loops based solely on mechanical properties of tissues: geometry, elasticity and relative growth. This should help to understand how biophysical and biochemical events drive tissue development.

Gut folding

Nature **476,** 57–63 (2011)



The gut in vertebrates is a folded tube attached to the mesentery — a sheet-like structure that connects the tube to the abdominal wall. Attempts have been made to explain the origin of the gut's characteristic looped patterns, which are reproducible in individual organisms but show variations across species, by invoking distinct diets and packing constraints in body cavities. Mahadevan and colleagues, using a combination of experiments, simulations and scaling laws, now show that the size and shape of the folds in the vertebrate gut can be described quantitatively by a simple theory that accounts for the differential growth between the tube and the mesentery, and for the geometric and elastic properties of these two tissues. To show this, they built a synthetic replica of the gut that consists of a stretched thin rubber sheet (the mesentery) stitched along its boundary to an unstretched, straight rubber tube — the imposed differential strain mimicking the differential growth of the two tissues. When allowed to relax, the rubber model folded into a structure reminiscent of the natural gut. *PP*

Out of the wire

Nano Letters **11,** 2584–2589 (2011)

(Ga,Mn)As is the model ferromagnetic semiconductor, used to demonstrate prototype devices that merge the suitability of semiconductors for electronics with magnetism. Unfortunately the Curie temperature T_C has never gone beyond 190 K, a real obstacle for the material to become mainstream. Lin Chen *et al.* have now increased T_C to 200 K by making (Ga,Mn)As nanowires. The main problem so far has been doping with Mn atoms. The more Mn is introduced to substitute Ga, the higher T_C, in principle. However, beyond a certain threshold Mn atoms locate between Ga atoms rather than substituting them, which in fact decreases T_C. A way to get rid of interstitial Mn atoms is to diffuse them out by thermal annealing. By patterning their material in nanowires, Lin Chen and colleagues have increased the surface available for the interstitial to diffuse out. They increased T_C from an original 160 K to 200 K, but it may go even higher. It may not always be true, but in this case going to the nanoscale certainly helps. *FP*

Beating in sync

Science **333,** 456–459 (2011)

Cilia and flagella — tail-like protrusions that some cells have — can undergo self-sustained beating patterns that drive active cell motion. In eukaryotic cells, the core of these protrusions consists of an ordered bundle of microtubules and, among hundreds of proteins, dynein motors. Dyneins cause neighbouring microtubules to slide against each other by walking on a microtubule while being attached to an adjacent one. Elastic connectors between microtubules transform sliding into bending, and the regulated activity of thousands of dyneins causes oscillatory beating. Zvonimir Dogic and colleagues have now found a minimal *in vitro* system that mimics the beating patterns of cilia. The system is composed of microtubules, clusters of kinesin motors and a non-adsorbing polymer. Entropic depletion of the polymer drives microtubule bundling, whereas microtubule–kinesin interactions cause the bundled microtubules to beat as in native cilia. Surprisingly, dense arrays of active bundles spontaneously beat in sync, just as ciliary fields do. Such a minimal system could serve to further decipher the mechanistic origin of the synchronized beating of cilia and flagella. *PP*

Natural plasmonics

Nano Letters http://dx.doi.org/10.1021/nl2018959 (2011)

The light-enhancing effects of plasmonic devices have been widely recognized to be able to boost the performance of solar cells. Mostafa El-Sayed and colleagues now apply this capability to a natural light-harvesting system — the membrane protein bacteriorhodopsin (bR). Used by some bacteria, this protein captures light and uses this energy to create a proton difference across its membrane. This separation of electrical charges has been successfully used to power electrochemical cells, although the observed photocurrents have remained rather low. A problem with the efficiency of the bR photocycle is a bottleneck in the conversion of an intermediate, photoexcited molecular state back to the original state of the protein. This slow conversion can be sped up by the absorption of blue light, but this process hasn't been very efficient. El-Sayed and colleagues now deploy silver nanoparticles in the bR electrochemical cells. The plasmon resonance has been tuned to the blue-light-absorption region of bR so that the large field enhancement close to the nanoparticles accelerates the relaxation of the intermediate state. As a consequence, the photocurrents observed are up to 5,000 times higher than without plasmonic enhancement. *JH*

DNA lithography

J. Am. Chem. Soc. **133,** 11868–11871 (2011)

The design of DNA molecules that readily fold into arbitrary shapes — DNA origami — holds promise for the bottom-up fabrication of nanoscale devices, both through DNA-directed self-assembly and nanopatterning processes. The patterning of inorganic substrates with DNA templates usually requires the deposition of intermediate mask layers as these molecules are sensitive to common dry etchants. Haitao Liu and colleagues now show that SiO_2 surfaces can be patterned using self-assembled DNA alone in a vapour-phase etching process. Owing to a difference in affinity towards H_2O, deposited DNA molecules modify the local water concentration on SiO_2 surfaces. The etching rate of these surfaces with HF gas, in turn, increases in the presence of adsorbed water. The researchers exploit this dependence to modulate the etching rate in close vicinity of the DNA molecules. Depending on the relative humidity of the environment, this process allows them to fabricate trench or ridge patterns with feature sizes below 20 nm. On further refinement the method could reach molecular-scale resolution and enable the patterning of additional layers underneath the SiO_2, the researchers suggest. *CM*

Written by Joerg Heber, Pep Pàmies, Fabio Pulizzi and Christian Martin.