transmitted from the motor to the rotor because of insufficient steric interaction. Thus, the motor acts merely as a switch.

In the design of Štacko *et al.*, a naphthyl rotor was appended to the indanyl half of a second-generation rotary motor (see the figure, right) to secure the motion of the rotor with the light-powered rotation of the motor. Nuclear magnetic resonance and circular dichroism spectroscopy showed that during the complete rotation of the motor, the naphthyl paddle slides along and rotates around the fluorenyl unit, always facing it with the same side. Hence, the rotations around the rotor and the motor axes are locked and synchronized, like the motion of the Moon around Earth.

Leaving aside the stereochemical considerations required for a detailed understanding of the coupling mechanism, the key message conveyed by the study of Štacko *et al.* is that the transmission of motion relies on an appropriate tuning of the energy barriers associated with the different rotary motions. Another important requirement is the presence of diagnostic elements that enable the unambiguous experimental identification of the structures involved in the operation cycle. Both goals have been achieved by means of an ingenuous molecular design.

An important feature of the present system compared with previous examples of controlled movements transferred within synthetic molecular devices (*4*) is that the rotation generated by the motor is unidirectional, continuous, and autonomous (that is, it takes place under steady experimental conditions as long as light energy is available). Such extremely valuable properties are preserved upon transmission of motion. In living organisms, tasks ranging from signal transduction to motility are carried out by propagating molecular movements via mechanical connections. Although we are still far from reaching similar goals with artificial systems, the field of molecular machines is rapidly progressing, and elements now exist for taking up the challenge of making sophisticated nanoscale devices by coupling mechanical parts. ■

REFERENCES

1. V. Balzani, A. Credi, M. Venturi, *Molecular Devices and Machines—Concepts and Perspectives for the Nanoworld* (Wiley-VCH, 2008).
2. C. J. Bruns, J. F. Stoddart, *The Nature of the Mechanical Bond: From Molecules to Machines* (Wiley, 2016).
3. D. A. Leigh, *Angew. Chem. Int. Ed.* **55**, 14506 (2016).
4. T. Muraoka, K. Kinbara, T. Aida, *Nature* **440**, 512 (2006).
5. P. Štacko *et al.*, *Science* **356**, 964 (2017).
6. H. Iwamura, K. Mislow, *Acc. Chem. Res.* **21**, 175 (1988).
7. S. Ogi, T. Ikeda, R. Wakabayashi, S. Shinkai, M. Takeuchi, *Chem. Eur. J.* **16**, 8285 (2010).
8. S. Liu *et al.*, *Angew. Chem. Int. Ed.* **54**, 5355 (2015).
9. M. K. J. ter Wiel, R. A. van Delden, A. Meetsma, B. L. Feringa, *Org. Biomol. Chem.* **3**, 4071 (2005).

10.1126/science.aan4353

MICROBIOME

A microbiome variable in the HIV-prevention equation

Vaginal microbes thwart an antiretroviral microbicide

By **Susan Tuddenham** *and* **Khalil G. Ghanem**

The healthy vaginal microbiota is typically characterized by the predominance of *Lactobacillus* species (including *L. crispatus, L. jensenii, L. gasseri,* and *L. iners*). These bacteria are thought to protect against pathogens through a variety of mechanisms, including competitive inhibition, secretion of bacteriocins (substances that inhibit the growth of bacteria), and the production of lactic acid, which lowers the vaginal pH and has immunomodulatory effects (*1*). Consequently, vaginal dysbiosis is currently defined by the presence of polymicrobial bacterial populations with reduced or absent lactobacilli. This lactobacillus state characterizes bacterial vaginosis, a clinical condition that is a common cause of vaginal symptoms in reproductive-aged women (*2*). Decreased bacterial diversity in the gut has been linked to a number of pathologic conditions (*3*), whereas increased vaginal bacterial diversity has been associated with a variety of poor patient outcomes including preterm birth and the acquisition and spread of sexually transmitted infections (*4, 5*). On page 938 of this issue, Klatt *et al.* (*6*) add to this list a decrease in the efficacy of the vaginal antiretroviral gel tenofovir to prevent HIV acquisition.

"...without a deeper understanding of the... vaginal microbiome, successful interventions... will remain elusive."

Klatt *et al.* used samples collected from a subset of participants in a randomized controlled trial that evaluated the efficacy of tenofovir intravaginal gel for the prevention of HIV acquisition in South African women (*7*). Using mass spectrometry to estimate microbial relative abundance in cervicovaginal lavage samples, the authors broadly grouped the samples into *Lactobacillus*-dominant, or diverse, non–*Lactobacillus*-dominant categories. The authors found that even in women with high drug adherence, vaginal tenofovir concentrations were lower and the drug was substantially less efficacious in preventing HIV acquisition in the non–*Lactobacillus*-dominant group. In vitro studies showed that *Gardnerella vaginalis* and other anaerobes metabolized tenofovir, but two *Lactobacillus* species did not. There are important limitations in the data that the authors acknowledge, such as a cross-sectional design that fails to take into account the temporal dynamics of the vaginal microbiota, the absence of clinical information on bacterial vaginosis, and the lack of a mechanism for tenofovir metabolism. Nevertheless, the findings of Klatt *et al.* are strengthened by other in vitro *(8)* and human studies (*9*).

As understanding of the vaginal microbiota and its potential impact on women's health continues to develop, the study by Klatt *et al.* highlights the importance of "pharmacomicrobiomics"—a term that reflects the study of drug-microbiota interactions (*10*). The finding that components of the human microbiota may affect the concentration of a drug in vivo is not without precedent. The ability of specific gut bacteria to metabolize medications is well established. One of the best-known examples is digoxin, a drug used to treat various heart conditions. Metabolism of digoxin was recently attributed to *Eggerthella lenta* (*3*). Although the mechanistic details of how *G. vaginalis* and other anaerobes metabolize tenofovir are not defined, Klatt *et al.* show that individual variability in tenofovir concentrations among study participants goes beyond drug adherence, thereby adding yet another variable to the HIV-prevention equation.

The introduction of "multiomic" technologies to examine nucleic acid, protein, and other profiles, elicited high hopes that the mysteries of vaginal eubiosis and dysbiosis—that is, optimal and suboptimal vaginal bacterial communities—would be

Department of Medicine, Division of Infectious Diseases, Johns Hopkins University School of Medicine, Baltimore, MD, USA. Email: kghanem@jhmi.edu

quickly elucidated. Although the study by Klatt *et al*. simply grouped participants into *Lactobacillus*-dominant (i.e., eubiotic) and non–*Lactobacillus*-dominant (i.e., dysbiotic) groups, emerging data now hint that the complexities of these conditions are considerably more nuanced, perhaps an important lesson for the broader field of microbiota research. Molecular techniques that enable species-level classification of Lactobacilli suggest that not all Lactobacilli are created equal with respect to their ability to protect the female reproductive tract. For example, vaginal microbiota dominated by *L. iners* have been associated with increased acquisition of sexually transmitted infections (*11*) and preterm birth (*12*). There is emerging evidence that within the same species, different strains of *L. iners* may be more or less beneficial (*13*). Similarly, strain-specific differences in the anaerobe *Gardnerella* have been documented (*14*).

Precision medicine, defined by the U.S. National Institutes of Health as "an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment, and lifestyle for each person," must also account for the variability of the individual's microbiota. This raises a critical question: Can a woman's vaginal microbiota be altered? Unfortunately, dysbiosis is difficult to treat: Although in the short-term, antibiotic therapy substantially alters the structure and composition of the vaginal microbiota in women with bacterial vaginosis, nearly 60% will have a recurrence within a year following therapy (*15*). Thus, effective antibiotic-sparing pre- and probiotics are actively being sought.

To date, variability in study designs, outcomes (prevention versus treatment of dysbiosis as well as methods of measurement of the vaginal microbiota), and strains limit the ability to draw definitive conclusions on probiotic efficacy. The study by Klatt *et al*. is a reminder that without a deeper understanding of the structure, function, and dynamics of the vaginal microbiome, successful interventions to optimize it and improve women's health will remain elusive. ■

REFERENCES AND NOTES

1. D. H. Martin, J. M. Marrazzo, *J. Infect. Dis.* **214** (suppl. 1), S36 (2016).
2. A. B. Onderdonk, M. L. Delaney, R. N. Fichorova, *Clin. Microbiol. Rev.* **29**, 223 (2016).
3. S. Tuddenham, C. L. Sears, *Curr. Opin. Infect. Dis.* **28**, 464 (2015).
4. R. M. Brotman, *J. Clin. Invest.* **121**, 4610 (2011).
5. K. Murphy, C. M. Mitchell, *J. Infect. Dis.* **214** (suppl. 1), S29 (2016).
6. N. R. Klatt *et al*., *Science* **356**, 938 (2017).
7. Q. Abdool Karim *et al*., *Science* **329**, 1168 (2010).
8. R. B. Pyles *et al*., *PLOS ONE* **9**, e93419 (2014).
9. S. L. Hillier *et al*., Impact of Vaginal Microbiota on Genital Tissue and Plasma Concentration of Tenofovir, abstract 87-BL, Conference on Retroviruses and Opportunistic Infections, Seattle, WA, 2017.
10. M. ElRakaiby *et al*., *OMICS* **18**, 402 (2014).
11. C. van der Veer, S. M. Bruisten, J. J. van der Helm, H. J. de Vries, R. van Houdt, *Nephrol. Dial. Transplant.* **64**, 24 (2017).
12. L. M. Kindinger *et al*., *Microbiome* **5**, 6 (2017).
13. M. I. Petrova, G. Reid, M. Vaneechoutte, S. Lebeer, *Trends Microbiol.* **25**, 182 (2017).
14. D. W. Hilbert *et al*., *Eur. J. Clin. Microbiol. Infect. Dis.* 10.1007/s10096-017-2933-8 (2017).
15. C. S. Bradshaw *et al*., *J. Infect. Dis.* **193**, 1478 (2006).

ACKNOWLEDGMENTS

We are grateful to C. L. Sears, R. Brotman, and R. McKenzie for their insights and thoughtful review of the manuscript. Funding is through the U.S. National Institute of Allergy and Infectious Diseases: K23AI125715 (S.T.), R01AI089878 (K.G.G.), U19AI084044 (S.T. and K.G.G.).

10.1126/science.aan6103

The microbicide tenofovir prevents retroviral replication. As a vaginal gel, it offers a feasible method for preventing HIV infection.

PHOTO: MICROBICIDE TRIALS NETWORK

APPLIED PHYSICS

Applying plasmonics to a sustainable future

Plasmonic technologies may form components of a future clean and sustainable society

By **Alberto Naldoni,[1,2] Vladimir M. Shalaev,[1] Mark L. Brongersma[3]**

Chemistry is fundamental for powering our society. A flurry of very promising experiments demonstrate that plasmonics may have a transformative impact on the way we will drive, manipulate, enhance, and monitor chemical processes in the future. Plasmonics offers the ultimate spatial and temporal control over light and photochemistry, with the help of metallic nanostructures capable of concentrating electromagnetic energy into nanoscale volumes. Surface plasmons (SPs) are charge-density oscillations at the surface of a conducting material and decay by reemission of a photon or through the creation of highly energetic ("hot") electrons and holes. The subsequent equilibration of hot carriers with lattice phonons can lead to appreciable local heating.

All these physical phenomena can be leveraged to efficiently produce fuels and chemicals. One example is the use of resonant nanostructures combined with semiconductor photocatalysts to increase the rate of interband transitions or to extend light harvesting to sub-bandgap photons (*1*, *2*). Plasmonic or high-index dielectric nanostructures could be used to engineer ultrathin semiconductor layers, which, through field-enhancement or light-trapping effects, reach broadband near-unity absorption with an accompanying reduction in materials and device cost. In contrast to semiconductor photocatalysis, hot-carrier–driven transformations on metal surfaces offer the opportunity to explore new

[1]*School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47907, USA.* [2]*Regional Center of Advanced Technologies and Materials, Faculty of Science, Palacký University, Šlechtitelů 11, 78371 Olomouc, Czech Republic.* [3]*Geballe Laboratory for Advanced Materials, Stanford University, Stanford, CA 94305, USA. Email: shalaev@purdue.edu*

Editor's Summary

A microbiome variable in the HIV-prevention equation

Susan Tuddenham and Khalil G. Ghanem (June 1, 2017)

Science **356** (6341), 907-908. [doi: 10.1126/science.aan6103]

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published weekly, except the last week in December, by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005.