their epidermal layer were wounded, there was a significant increase in new hair follicles compared with mice with normal Wnt activity. As these cellular events seem to recapitulate those seen in embryonic development, it is possible that hair formation during embryogenesis and following wounding share several signalling pathways, including Wnt.

What are the essential criteria for triggering the formation of new hair follicles in a patch of adult skin? The size of the healed wound seems to be critical. This implies that an 'embryonic skin-like field' must be established first. Self-organization of hair follicles then progresses, and periodically arranged primordia (aggregates of embryonic cells that indicate the first traces of a structure) emerge. As new hair patterns after wounding are not predetermined, it is possible to manipulate the number and size of the follicles through positive- and negative-feedback regulation of inhibitors and activators of signalling pathways such as Wnt[10,13].

Adult organisms contain several types of cells with remarkable regenerative potential[12,14,15] — if we could only provide the appropriate chemical and physical environment. The best teacher for this is nature. Indeed, an event that parallels the work of Ito and colleagues is the regeneration of deer antlers. After an antler is cast, the large open wound that forms is followed by re-epithelialization and the development of new hair follicles, as well as budding of the new antler[16]. Further studies on animal models should reveal other unexpected and ingenious ways of awakening stem cells with appropriate environmental cues when regeneration is needed[10].

Repair and regeneration seem to be competing processes. As closing wounds fast is essential for survival, repair often dominates. Regenerative medicine promises to identify natural healing power and a shift from repair to regeneration. Thus, by simply altering the environment of stem cells[10] during wound healing, future wounds might heal with appendages reformed. As human and mouse skin heals differently, the results of Ito *et al.*[1] are yet to be verified in humans. However, these findings will undoubtedly inspire new thinking in the management of alopecia, in tissue engineering and in the regeneration of other organs. ■

Cheng-Ming Chuong is in the Department of Pathology, Keck School of Medicine, University of Southern California, Los Angeles, California 90033, USA.
e-mail: chuong@pathfinder.usc.edu

1. Ito, M. *et al. Nature* **447,** 316–320 (2007).
2. Kligman, A. M. & Strauss, J. S. *J. Invest. Dermatol.* **27,** 19–23 (1956).
3. Billingham, R. E. & Russel, P. S. *Nature* **177,** 791–792 (1956).
4. Breedis, C. *Cancer Res.* **14,** 575–579 (1954).
5. Lacassagne, A. & Latarjet, R. *Cancer Res.* **6,** 183–188 (1946).
6. Ito, M. *et al. Nature Med.* **11,** 1351–1354 (2005).
7. Levy, V. *et al. Dev. Cell* **9,** 855–861 (2005).
8. Claudinot, S. *et al. Proc. Natl Acad. Sci. USA* **102,** 14677–14682 (2005).
9. Levy, V., Lindon, C., Zheng, Y., Harfe, B. D. & Morgan, B. A. *FASEB J.* **7,** 1358–1366 (2007).
10. Chuong, C.-M., Wu, P., Plikus, M., Jiang, T. X. & Widelitz, R. B. *Curr. Top. Dev. Biol.* **72,** 237–274 (2006).
11. Silva-Vargas, V. *et al. Dev. Cell* **9,** 121–131 (2005).
12. Fuchs, E. *Nature* **445,** 834–842 (2007).
13. Maini, P. K., Baker, R. E. & Chuong, C.-M. *Science* **314,** 1397–1398 (2006).
14. Jahoda, C. A. & Reynolds, A. J. *Lancet* **358,** 1445–1448 (2001).
15. Toma, J. G. *et al. Nature Cell Biol.* **3,** 778–784 (2001).
16. Croft, N. J. & Randall, V. A. in *Hair Science & Technology* (ed. Van Neste, D.) 69–74 (Skinterface, Tournai, Belgium, 2003).

OPTICS

Beyond diffraction

Evgenii E. Narimanov and Vladimir M. Shalaev

A material with a cunningly designed optical response overcomes a fundamental limit to image resolution. This 'hyperlens' produces magnified images of objects smaller than the wavelength of the imaging light.

When an object is illuminated, information about features smaller than the wavelength of the incident light is carried in evanescent waves, whose amplitudes decrease exponentially with distance. This rapid decay means that detail is lost when an image of the object is viewed in its far field. Two papers published in *Science*[1,2] contain experimental details of a 'hyperlens' that circumvents this problem, turning evanescent fields into propagating waves, and so producing magnified far-field images of sub-wavelength structures.

For propagating electromagnetic waves, the wavelength defines the scale over which the accompanying electromagnetic field varies. When an object is moved by a distance much smaller than this wavelength, it will be subjected to essentially the same field as before, and an image formed by the light scattered off the object will also remain unchanged. The light's wavelength therefore gives a measure of the image resolution, generally referred to as the Abbe diffraction limit[3], after the nineteenth-century German physicist Ernst Abbe.

At the heart of the hyperlens concept[4,5] lies a nanostructured 'metamaterial' whose dielectric constant — a measure of a material's response to the electric field of the incident light — has opposite signs in two orthogonal directions. The effect of this anisotropy is to do away with the lower limit on the wavelength of a propagating field that is characteristic of a conventional, isotropic medium. With no lower limit on the propagating light's wavelength, there is no diffraction limit — and so, theoretically, unbounded image resolution.

As soon as waves of very small wavelength emerge from this 'optical hyperspace' into air, however, they can no longer propagate, and again become evanescent. To deliver the sub-wavelength information carried by such waves into the far field, one must first increase their wavelength to the point when propagation in air is possible. The cylinder (or half-cylinder) geometry of the hyperlens is specifically designed to achieve this, by slowly increasing the wavelength as the field spreads away from the centre of the device (Fig. 1).

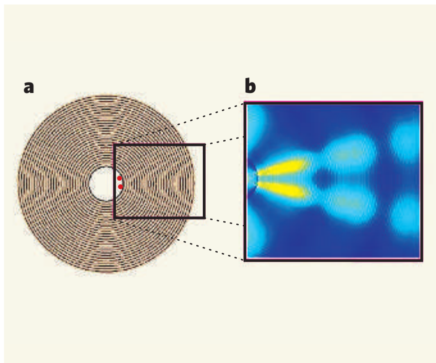

Figure 1 | How to build a hyperlens. a, As theoretically proposed[4,5], a hyperlens consists of a (half-)cylindrical layered object that has dielectric constants of different signs across the layers (radial axis) and along the layers (tangential axis). The target to be imaged (here, two point sources, red) would, in a practical realization, be illuminated from the top (into the plane of the page) or from the side, in which case half of the cylinder is cut away. b, Although the distance between these point sources is significantly smaller than the wavelength of the illuminating light, the effect of the anisotropic hyperlens medium is to progressively increase the distance between their 'images' until, at the outer surface, it is larger than the wavelength, and can be resolved by a conventional microscope. (Figure adapted from ref. 4.)

In their experimental realizations of the hyperlens, Liu *et al.*[1], of the University of California, Berkeley, and Smolyaninov *et al.*[2], of the University of Maryland, Baltimore, use a half-cylinder[1] and a cylinder[2] of layered metamaterials whose dielectric constant is strongly isotropic in the radial and tangential directions. The objects to be imaged are placed in the hollow middle and illuminated from the outside — in Smolyaninov and colleagues' case, from the top of the cylinder, and for Liu and colleagues from the side of the half-cylinder.

The two groups differ in their methods for achieving the necessary strong anisotropy in their hyperlens medium. Liu *et al.*[1] use a curved, periodic stack of silver and aluminium oxide deposited on their half-cylinder cavity, which is fabricated on a quartz substrate. They use this system to produce an image of a pair of lines with sub-wavelength spacing and the letters 'ON', both with sub-diffraction resolution.

Smolyaninov *et al.*[2], on the other hand, combine the idea of a hyperlens with the earlier concept of the superlens[6]. A superlens is made of a single layer of material with a negative refractive index. Rather than immediately converting evanescent waves into propagating fields, a superlens enhances the evanescent waves through resonant coupling to fields on the surface of the lens known as surface plasmon polaritons. In Smolyaninov and colleagues' device, formed of concentric rings of the plastic polymethyl methacrylate (PMMA) on a gold surface, the evanescent waves experience such a boost, in addition to the device's strong anisotropy. The magnifying action of this lens is demonstrated by imaging rows of two or three PMMA dots placed near the inner ring of the device.

These novel imaging devices[1,2] have significant advantages over traditional approaches, and should therefore find numerous applications in optical imaging. Above all, they produce a direct optical image, and so do not require the time-consuming scanning process of near-field scanning optical microscopy.

Recently, the Berkeley group has also developed an alternative approach to the far-field superlens[7], in which the conversion from evanescent to propagating waves is achieved through scattering on surface corrugations. Although it is still too early to tell which of these devices will prove the most useful, the recent explosive progress in sub-wavelength imaging undoubtedly opens up many exciting possibilities. ■

Evgenii E. Narimanov and Vladimir M. Shalaev are in the Department of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana 47907, USA.
e-mails: evgenii@purdue.edu; shalaev@purdue.edu

1. Liu, Z., Lee, H., Xiong, Y., Sun, C. & Zhang, X. *Science* **315,** 1686 (2007).
2. Smolyaninov, I. I., Hung, Y.-J. & Davis, C. C. *Science* **315,** 1699–1701 (2007).
3. Abbe, E. *Arch. Mikrosk. Anat. EntwMech.* **9,** 413–468 (1873).
4. Jacob, Z., Alekseyev, L. V. & Narimanov, E. *Opt. Express* **14,** 8247–8256 (2006).
5. Salandrino, A. & Engheta, N. *Phys. Rev. B* **74,** 075103 (2006).
6. Pendry, J. B. *Phys. Rev. Lett.* **85,** 3966–3969 (2000).
7. Liu, Z. *et al. Nano Lett.* **7,** 403–408 (2007).

ECONOMIC ECOLOGY

In the market for minke whales

Stephen R. Palumbi

The capture–recapture technique is a mainstay of ecology. This principle has been applied with individual genotyping to estimate how many accidentally killed minke whales reach the markets of South Korea.

Behind this stack of parboiled strips of fatty skin, and red meat with thick strips of blubber (Fig. 1), lies a story of scientific detective work. The picture shows a shop in South Korea where the whale products for sale could have come from an endangered population of minke whales from the East Sea, elsewhere called the Sea of Japan. Despite the ban on commercial whaling administered by the International Whaling Commission (IWC), this sale is probably perfectly legal: whales accidentally entangled and killed by fishing gear in the East Sea can be sold for food, as long as the accidental death is reported.

But how many whales really suffer this fate? Writing in *Molecular Ecology*, Baker and colleagues[1] describe how they have developed a genetic capture–recapture method to tackle this question. They conclude that some 827 whales were killed and sold this way during their five-year study — far more than the 458 reported to the IWC.

Minke whales in the East Sea make up a distinct population referred to by the IWC as the J stock, which suffered severe declines until the moratorium on commercial whaling began in 1986. Despite the ban, meat from this population continued to be found in Asian markets[2], and these animals were eventually traced to whales accidentally drowned by fishing gear. After the genetic detection of J-stock animals in Japanese markets, Japan and Korea began reporting whales that were mistakenly killed — up to 150 in some years, but usually far fewer. The reported value of a minke whale (at least US$30,000 each) underscores the difficulty of protecting this population from exploitation[3].

Baker *et al.*[1] took the approach of market ecologists, setting up a genetic capture–recapture study. Mark–recapture surveys in ecology seek to estimate the number of animals in a population by releasing a known number of marked individuals, and then estimating total population size based on the fraction of marked individuals recaptured[4]. Capture–recapture methods use individual identification tools such as DNA genotype analysis instead of marks[5]. And like a typical experiment in ecology, the chance of identifying the same whale twice in a market depends on the whale's 'lifespan' in the market — how long meat samples from an individual whale last before they are all sold. To estimate this figure, a co-author, Justin Cooke, developed

N. BEHRING-CHISHOLM/GREENPEACE

Figure 1 | Whale for sale. **This parboiled minke-whale meat from the East Sea (Sea of Japan) is on offer at a shop in South Korea. A five-year estimate[1] based on individual genetic identification of whale products in South Korea shows that almost twice the number of minke whales were accidentally killed in fishing gear compared with official estimates. Especially given the large number of minkes from the same population that are accidentally killed and landed in Japan, this rate of loss is likely to be unsustainable.**