cents (US) and reducing the cost to below 10 cents may take several years. For some applications, 20 cents is acceptable, however, for others it is a showstopper. For example, consider replacing product bar codes with RFID tags. As an accepted part of product packaging bar codes are essentially free and RFID tags must compete by providing reduced labour costs and error rate, with perhaps some premium for improved function. It is likely the tag cost would need to be near 1 or 2 cents to allow wide RFID bar-code replacement.

Steudel and colleagues demonstrate that organic electronic devices can easily provide the performance required for one of the critical tasks in RFID tag operation: efficient power generation from a radio-frequency field. Because many tags operate at 13.56 MHz, and because this frequency allows convenient antenna size, operation at this frequency, or even higher, is a prerequisite for organic electronic RFID tags. Steudel, *et al.* demonstrate that operation at frequencies up to 50 MHz is readily obtained with a simple device structure and fabrication process, and that much higher frequency operation, perhaps up to 1 GHz, may also be possible.

Much more development is required for organic electronic RFID tags to appear and successfully compete with silicon. Low-cost patterning and low-cost processing must be developed in the difficult context of a low-cost commodity product. It is certainly possible that RFID tags will not turn out to be a fertile area for organic electronics application. However, non-Moore's Law solutions will increasingly be the key for future microelectronic progress, and the demonstration of compatibility with high-frequency signals is an important tool in the organic electronics toolbox.

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MATERIAL WITNESS

Body painting

There is something curious about the concept of 'bioprinting'. It is an exciting and potentially valuable approach to tissue engineering, but the prospect is akin to recreating an Old Master's painting by painstakingly positioning each pigment particle where in the original they were deposited by the stroke of a brush. It might precipitate new questions about our bodies' dynamic architecture.

The most common technique for creating artificial tissues involves growing cells on a polymer scaffold. Artificial skin for grafts has been made this way for years from fibroblasts cultured within a biodegradable, porous scaffold of a material such as collagen. Three-dimensional tissues — artificial organs — are more challenging, however, because of the issue of vascularization.

Without a blood supply, seed cells deep within a scaffold matrix will quickly die. One option is to first grow the vasculature on an appropriately shaped tubular scaffold, and then to grow the other cells around it — a slow process at best. And it is hard, with the scaffold approach, to reproduce complicated, three-dimensional mixtures of cell types of the sort found in real organs.

Bioprinting aims to address these problems. It is basically an extension of the rapid-prototyping technology developed for making complex shapes in polymers and ceramics by building them up as a series of two-dimensional slices. Ink-jet technology is used to deposit the material in the form of an 'ink' that can be cured or sintered into a solid form.

For bioprinting, the ink consists of clusters of living cells that are printed onto thin sheets of soft polymer gel. A fresh sheet of this gel 'paper' is added for each successive layer, and the cells ultimately adhere to form cohesive, three-dimensional structures. Thomas Boland of Clemson University in South Carolina, for example, has produced tubes of contractile smooth muscle tissue from stacks of ring-shaped layers.

Viable cells can now be printed using nothing more sophisticated than commercial ink-jet printers. Multiple nozzles can create arbitrary structures of mixed cell types: Boland has demonstrated a nine-nozzle bioprinting system.

That bioprinting is approaching a true biomedical technology seemed clear at an international workshop on the topic at the Medical University of South Carolina, Charleston, in March 2005. In June, the university approved the establishment of a centre to develop the technique.

Yet the strikingly materialistic idea of reproducing an organically grown 3D body part by the 2D positioning of cells would force the issue of how much (and in what way) shape matters to function. Is it enough simply for the vascular system to be hierarchically branched, for example? Or (as some believe) might the precise scaling behaviour of the network structure, and the exact branching geometry — that is, the generative rules and the topological outcome of growth — matter for getting the correct flow properties and minimizing the pumping energy? There's no obvious reason why such a complex structure couldn't still be mimicked by bioprinting, yet it would highlight the fact that our bodies are not just arbitrary architectures of cells but frozen histories of the dynamic processes that made them.

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