EPSRC The Engineering and Physical Sciences Research Council

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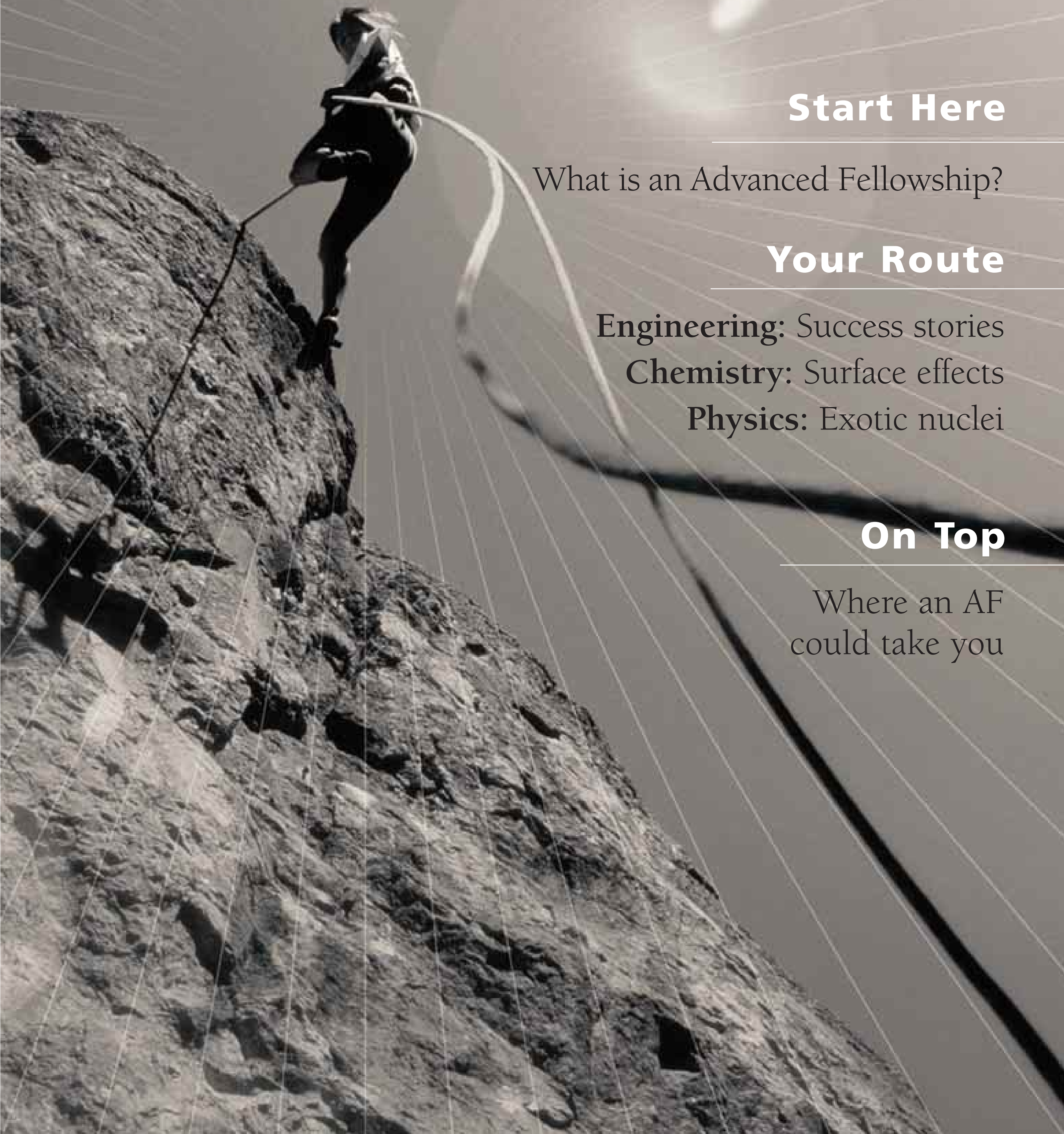
spotlight

Advanced Fellowships



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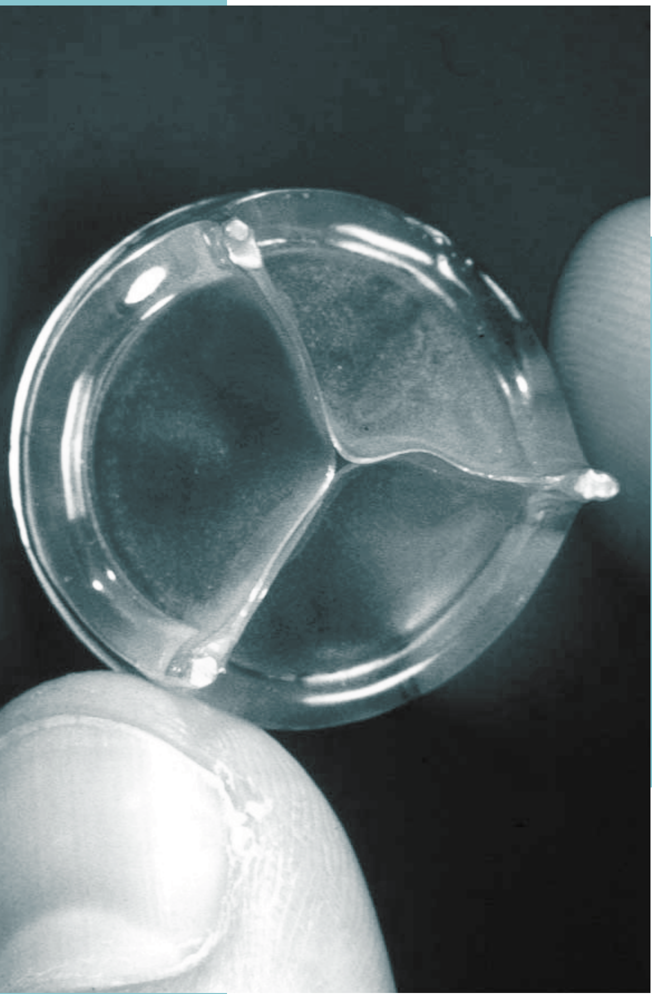


Engineering Success

By Tony Newton

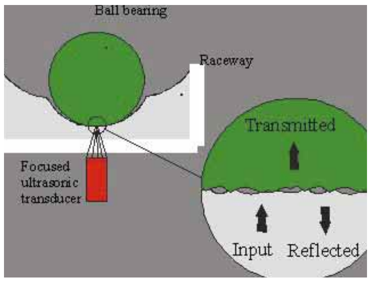
Making up almost a quarter of all current awards, engineering Advanced Fellows get the chance to tackle problems that affect everyone from oil prospectors to heart transplant patients. *Spotlight* picks out four success stories.

"In a sensor, we're converting mechanical energy into electrical energy and in a transmitter we're converting electrical energy into mechanical energy…"

Dr Sandy Cochran

There was a time when being an engineer meant that you built bridges, dug tunnels or were good with Meccano. Nowadays, however, it comes as no surprise that the 43 engineering Advanced Fellowships currently supported by EPSRC feature chemical engineers, mechanical engineers, electrical and electronic engineers, biomedical engineers, process engineers and aeronautical engineers. Given the diversity of engineering disciplines involved, what do the recipients of these prestigious awards have in common?

At the University of Paisley **Dr Sandy Cochran** is two years into her five-year Fellowship. Dr Cochran's field is ultrasonics and the possibilities offered by creating ultrasonic sensors from several thin layers rather than one thick layer. "Ultrasonic devices are used in lots of places but we tend to see the end result rather than the device. The most widely known application is probably the ultrasound scan in hospital but ultrasonics is an 'enabling' technology that's also used in burglar alarms, checking engines or pipelines for cracks, air bag deployment and parking sensors," explains Dr Cochran. "Ultrasonics is about creating sources of ultrasonic energy as well as sensing them. In a sensor, we're converting mechanical energy into electrical energy and in a transmitter we're converting electrical energy into mechanical energy, and that's where my work comes in."



Above: A diagram showing the ultrasonic response from the contact inside a ball bearing.

Ultrasound: Ultraloud

"Traditionally, ultrasonic transmitters usually comprise a single piece of piezoelectric material, and we face two key problems: First, it's impossible to manufacture the material thick enough for some jobs. For example, low ultrasonic frequencies, in the region of 30 kilohertz, would require a single piece of piezoelectric material some 5 cm thick. Secondly, electrical impedance of a device depends on the thickness of the material and the area. As the area is usually fixed by the particular application and the thickness by the frequency we want to work at, that means we're stuck with a specific electrical impedance which dictates the power output we can achieve." Dr Cochran's work to study novel ways in which transducers can be constructed from multiple, thinner layers of material has two significant potential benefits. "First, it allows high performance devices to be made thick enough to work at low ultrasonic frequencies. Less obviously, the electrical impedance of a device is governed by the thickness and number of the layers. Two layers have a quarter of the impedance, three layers a ninth, and so on. So we also get more power out more easily from multiple layers."

Asked why it's more important to get more power out, Dr Cochran explains that it's rather like shouting in front of a cliff. The louder you shout, the further away you can be and still hear the echo. So with ultrasound more power means more penetration depth into the object under study, be it in underwater sonar, medical imaging or remote sensing. Creating new transducer technologies is clearly something that Dr Cochran enjoys doing but how has his Advanced Fellowship affected his work and its direction? "Having been a contract researcher for fourteen years prior to the Fellowship, I'd had the day-to-day freedom of any University research but the overall direction was almost always set in advance. Now, the award gives me the freedom to say 'I don't know' or 'what can I do with this?' and to follow up interesting avenues with fewer of the teaching and admin distractions of a normal lecturing job. Another area in which the

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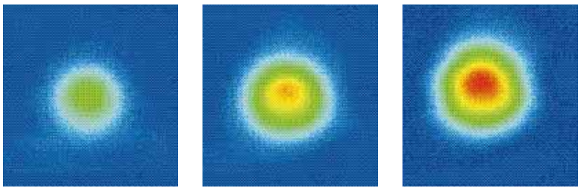

This diagram shows how Dr Drinkwater uses a focused beam of ultrasound to probe solid objects.

Fellowship has made a big difference is in the ability to collaborate widely. As a contract researcher, that collaboration is 'built in', whereas the Fellowship encourages me to network widely and to seek new ways to turn interesting intellectual property into useful products." Dr Cochran sees AFs as especially important in the setting up of new research groups, he concludes: "The Fellowship comes at just the right point in a person's career to do that – you have enough experience to start the group, but you're not too old to be risk averse."

Dr Bruce Drinkwater is also researching ultrasonics. Based at the University of Bristol, Dr Drinkwater's Fellowship has been going for a year and a half and he sees it as an umbrella for a number of research projects which fall broadly into two streams. The first of these is adhesive bonding: "The problem is that whilst we know how to test a metal spot weld ultrasonically to tell whether it is satisfactory, we're much less good at that when it comes to adhesive techniques. The lack of good, non-destructive testing techniques still limits adhesive applications in car and ship building, although the aerospace industry has a rather better handle on things," observes Dr Drinkwater. "Some industries don't use adhesives where they could do, because they don't have a satisfactory method of testing. One of the things we're trying to do is to understand the physical nature of an adhesive defect in order to model what is going on more accurately. We are trying to use high-power ultrasound to detect these defects and that boils down to choosing the correct amplitude of ultrasonic wave. If the amplitude is too high we end up melting the joint and if it's too low we don't see anything, so there's a small window of opportunity."

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Dr Bruce Drinkwater

Mind the gaps

The second stream of Dr Drinkwater's work relates to characterising solid-solid interfaces. "To the naked eye, a bolted joint or interlocking gear wheels may appear to be in contact across their entire surface but the microscopic reality is that all surfaces are rough and only contact each other 'peak to peak'" explains Dr Drinkwater. "This means that the real contact area between two machine components is small, and there will be high stresses at the contacting peaks of the surface roughness. This has major implications for friction, wear and component life, and ultrasound can play a part both in helping to optimise design of such components and in monitoring the extent of the contact and the thickness of any air gaps or lubricating film between the components." >>

A sub-sea drill bit. Dr Neville's project aims to understand how parts like this corrode and wear under extreme environmental conditions.

"These components, which could be valve seats, bearings or pump impellers, must be able to withstand not only constant movement against other surfaces but also attack by corrosive gases or liquids."

Dr Anne Neville

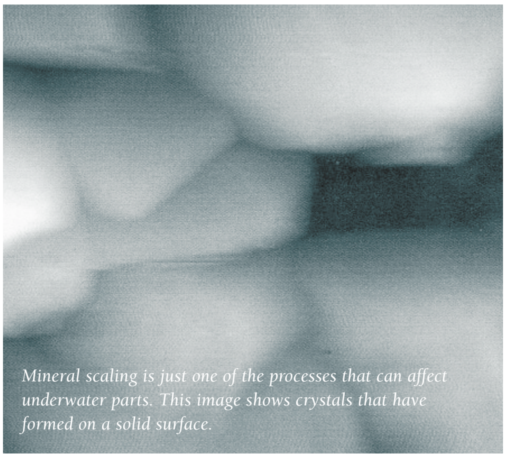
An ultrasonic beam incident on the interface between the two surfaces will be sensitive to the changing area of contact – it will pass through contacting areas but be reflected by the air gap or lubricating film. Because the technique is non-invasive and the transducers small, this technique can be used on-line and in real time to ensure that machinery is being optimally lubricated for best performance and long life.

For Dr Drinkwater it was time rather than ideas that were in short supply until the award of the Fellowship. "The Advanced Fellowship has allowed me to focus my energies and to free up time both to look into existing projects at a higher level and to consider new directions. I could dedicate myself to research but I volunteer to do some teaching on the basis that I was a lecturer for four years prior to applying for the Fellowship, and I'll have to go back to teaching and administration when it ends, so it's worth keeping my hand in!"

Like Dr Drinkwater, **Dr Anne Neville** and her team at Heriot-Watt University are looking at the interaction between mechanical moving parts but from a rather different perspective. Dr Neville's work falls into three areas; investigation of corrosion and erosion corrosion, lubrication and wear and mineral scaling. What links these three areas of interest is the emphasis on surface engineering and understanding processes occurring at 'real' engineering surfaces. "Components used in machinery within the oil exploration and chemical processing industries operate under extreme conditions of mechanical wear and in corrosive environments," Dr Neville explains. "These components, which could be valve seats, bearings or pump impellers, must be able to withstand not only constant movement against other surfaces but also attack by corrosive gases or liquids. Understanding degradation processes and the interaction of a surface with its environment is vital to be able to improve material performance and design new materials."

Battling corrosion

One way of improving resistance to wear is to coat the surface of the moving part with a ceramic/metal coating called a 'cermet'. A cermet consists of micrometre-size particles of ceramic material embedded in a matrix of metal alloy that can be up to half a millimetre thick. The ceramic phase supplies the required hardness and the metal matrix provides the medium for support. The High Velocity Oxy Fuel process is used to spray semi-molten metal onto a target surface through a torch. The mixture of hard ceramic and molten metal hits the target at several times the speed of sound and can be built up through multiple applications as a series of layers. "Cermet coatings are hard, and increase wear resistance but they are also liable to corrosion," says Dr Neville. "As the metal matrix corrodes, ceramic particles become exposed and their support is lost. In addition the metal corrosion can create a local environment severe enough to dissolve the ceramic component. This exposes more of the matrix to both wear and corrosive attack and ultimately leads to failure of the coating. We want to be able to understand how and why corrosion occurs at



Mineral scaling is just one of the processes that can affect underwater parts. This image shows crystals that have formed on a solid surface.

these points and use that information to apply intelligent design principles to produce better corrosion and wear-resistant coatings."

An important tool in this work is the atomic force microscope. By taking a sample of a coating material and placing it a corrosive environment, Dr Neville and her team can track the course of corrosion in real time at a microscopic/nanoscopic level. "We can use localised techniques to observe corrosive attack on cermet materials at the interface of metal and ceramic as it happens and link that to the electrochemistry. It's an iterative process, because you have to find out what is corroding. Is it the cobalt in the matrix or the tungsten in the tungsten carbide hard phase embedded within the matrix? Add to that the fact that corrosion can be both galvanic as a reaction between metals or steady state corrosion within the coating itself caused by localised features due to the geometry of the material, and you have a flavour of the task we face." Dr Neville heard about the Advanced Fellowship from colleagues who were familiar with the scheme. "What attracted me to the Fellowship was the ability to do full-time research for five years in a permanent position. I was awarded the Fellowship in 1999 and it came at a time when my research group was expanding rapidly. In 1997, we had six people. In 1999, we had twelve – and the group is now up to twenty." The problem, says Dr Neville, is that she will have to work out how to wind down to get back to lecturing when the Fellowship ends in 2004. Are there any additional benefits she could highlight? "These awards are pretty prestigious, so it does mean you get more recognition both academically and within industry. They also enable you to sit on an EPSRC panel, build contacts and gain a better insight into the funding process."

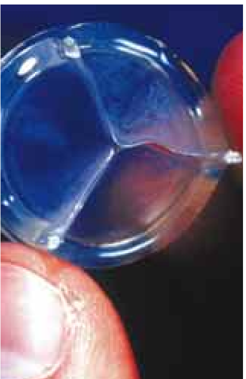
"The ideal would be to design a self-renewing valve that could last for the patient's remaining life."

Dr Nick Rhodes

Wear and tear to our bodies is something we all suffer from and modern medicine is extremely good at providing us with spare parts. However, good as these parts may be, **Dr Nick Rhodes** from the University of Liverpool believes that they could be made to last even longer. His Advanced Fellowship came along at exactly the right time: "The offer of a five-year grant to go and explore was quite enticing, especially when added to a guarantee that the university would keep me on afterwards. At around the same time as I was awarded the fellowship, we received a Joint Infrastructure Fund grant of over £3m to build a brand new lab which I had the pleasure of sitting down in front of autoCAD and designing. The lab was commissioned at about the same time as the Fellowship started, so I have the fantastic good luck to be able to do my own research in a brand new lab of my own designing."

Broken hearts

Dr Rhodes is interested in how and why polymers fail in biological environments and what can be done from a tissue-engineering viewpoint to improve the situation. Dr Rhodes cites an example of failure that will be familiar to many. "Conventional mechanical and porcine tissue heart valves suffer from different problems. Mechanical valves require lifelong anticoagulation (due to biocompatibility and flow-related effects) whilst tissue valves become stiff and haemodynamically useless after 10-12 years due to calcification. The ideal would be to design a self-renewing valve that could last for the patient's remaining life. One of our goals is to develop a tissue engineered valve core with a biologically stable lining of endothelial cells that expresses anticoagulant properties. This could then be used to construct a heart valve that manufactures its own anticoagulant to help keep the valve clean and functional."



An artificial heart valve: One day Dr Rhodes hopes it will be possible to produce a 'self-cleaning' heart valve with an extended lifespan.

The concept of tissue engineering involves the seeding of stem cells on a polymer scaffold. "Globally much effort has been put into defining how stem cells develop and much of the last two years of my research has been to develop stem cell models. My aim is to purify certain stem cell populations, grow them onto 'smart' scaffolds and nudge them into expressing the correct range of surface markers and receptors to have the desired anticoagulant effect." The scaffolds need to be 'smart' in terms of their chemistry, mechanical properties and their physical 3-D shape (orientation of fibres and size of pores). "The mechanical properties of the scaffold are key to encouraging stem cells to mature into the type of cells we want. Without the right sort of mechanical loading, we don't think the cells will differentiate into the desired type, so the design of the scaffold and its mechanical stimulation is a major element of the concept."

What all the engineering Advanced Fellows *Spotlight* talked to had in common was the belief that a Fellowship gave them the essential time and freedom to investigate. Whether it involved taking their studies of a previously visited area to a higher level or branching out to explore something new their AF enabled them to plan ahead, recruit a team and build a successful project. □

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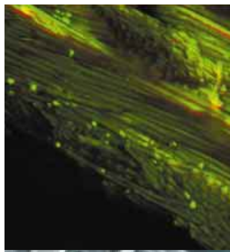

Top: Growing stem cells on a scaffold is one of the basic techniques of tissue engineering. Here mesenchymal stem cells are being grown.

Bottom: A tissue engineering scaffold. Designing a scaffold that will encourage stem cells to develop into the type of cell desired is a major challenge.