Cardiovascular medicine has benefited, both diagnostically and therapeutically, from dramatic advances that have occurred in catheter-based techniques. Today, as standard-of-care, we routinely measure pressure and flow in vessels, cardiac chambers and across valves, image the vasculature at high resolution, and therapeutically balloon-dilate and stent arteries and other cardiovascular structures. Despite these capabilities, new catheter-based techniques continue to emerge. Interventional cardiologists are universally excited by the anticipated regulatory approval of percutaneous valve systems and other structural heart technologies. Can we go further? The answer is yes, as a result of significant advances that have occurred in material science and micro/nanoelectronics. Recently, a class of novel materials has been developed: stretchable polymer-electronic composites. Utilizing these materials, a new class of catheters has been constructed, containing dense arrays of sensors and therapeutic modules. In this article we highlight the present and future status of integrating stretchable electronics with cardiovascular catheter systems.

Why have catheter-based techniques made such a dramatic difference in the practice of cardiology?

Catheters have allowed physicians to safely and steriley enter and traverse the vascular tree to diagnose and treat anato-pathologic conditions and diseases previously treated medically, often with limited efficacy, or surgically via open invasive procedures. The dramatic shift in the treatment of coronary artery disease (CAD) illustrates this point. Progressive CAD was initially treated medically, with patients being increasingly incapacitated by angina or ischemia-mediated ventricular dysfunction as disease progressed. A major advance occurred with the advent of coronary artery bypass grafting (CABG) allowing redirection of blood flow to ischemic tissue. While highly effective, CABG suffered the limitation of open chest surgery, prolonged recovery, early post-operative physical limitation, infection, bypass pump neurologic risk and limited lifespan for patency of the saphenous veins employed as graft conduits. The world changed in the late 1970s as balloon dilatation catheter technology was developed and percutaneous transluminal coronary angioplasty (PTCA) emerged. Within several years of adoption and growth, PTCA overtook CABG as the standard of care for advanced CAD. This trend has grown at an accelerated pace with the advent of stenting, with percutaneous catheter-based revascularization today being a standard-of-care, performed at a ratio of >4:1, compared with open-CABG surgery.

What do present catheters really do?

Catheters deconstructed

Fundamentally, catheters are elongated hollow tubular devices that afford percutaneous measurement or intervention, at a distance within the cardiovascular system. The long catheter shaft allows manual advancement and limited manipulation of the catheter tip from outside the patient to achieve deployment to a specific internal anatomic location. Recently, robotic and magnetic drive systems have been developed facilitating linear advancement, angulation and steering of catheters, although the use of these systems is largely investigational in interventional cardiology. The most basic catheter is a long hollow tube connected to a
If we could identify exuberant proliferation or thrombosis, this would be helpful. For instance, this could detect the propensity for restenosis and this would guide treatment decisions. If one resistance, stent non-passage and edge dissection, options. Similarly, if one could predict frictional factors, this would be of value in guiding treatment decisions. For example, if it was clear a priori that a lesion had eccentric calcium or rigid fibrous materials that would be non-yielding or have a high likelihood of fracture and dissection, this would be of value in guiding treatment options. Similarly, if one could predict frictional resistance, stent non-passage and edge dissection, this would guide treatment decisions. If one could detect the propensity for restenosis and thrombosis, this would be helpful. For instance, if we could identify exuberant proliferation or proinflammatory responders, this might help tailor choices as new stents, new drugs on stents and even biodegradable stents emerge. What is needed to accomplish this? The answer lies in the integration of enhanced diagnostic sensors, detectors and analytics on the catheter and potentially on the stent as well.

"Incorporating enhanced diagnostics, sensing and monitoring may finally get us into the domain of ‘see, interrogate and understand (know), treat and be confident.’"

Stretchable electronics

As with many innovations, breakthroughs occur when there is a marriage of otherwise disparate fields in new and useful ways. The fields of micro- and nanoelectronics and material science have greatly advanced over the past few years. All forms of electronic devices are increasingly becoming smaller, faster and more intelligent. Advances in chip design, processing power and sensor technologies have allowed the development of numerous forms of sensitive microelectronic and micromechanical systems. Micro- and nanosensors exist that can detect mechanical, chemical, optical, electrical, complex analyze, cellular and immunologic signals. Similarly, in material science, new advances have occurred, including the development of novel polymer systems, with enhanced mechanical properties, tissue compliance matching and biocompatibility. It is the combination of these electronic as well as material advances that has led to the recent breakthrough development of a novel class of materials, stretchable elastomer–nanoelectronic composites, for instance, stretchable electronics.

What else would be of value? What might we like to know?

Generically, the more information that can be provided as to the material, biochemical and cellular properties of the artery wall, the underlying atherosclerotic lesion or the post-interventional lesion, the better interventionalists would be equipped to make intelligent treatment decisions. For example, if it was clear a priori that a lesion had eccentric calcium or rigid fibrous materials that would be non-yielding or have a high likelihood of fracture and dissection, this would be of value in guiding treatment options. Similarly, if one could predict frictional resistance, stent non-passage and edge dissection, this would guide treatment decisions. If one could detect the propensity for restenosis and thrombosis, this would be helpful. For instance, if we could identify exuberant proliferation or proinflammatory responders, this might help tailor choices as new stents, new drugs on stents and even biodegradable stents emerge. What is needed to accomplish this? The answer lies in the integration of enhanced diagnostic sensors, detectors and analytics on the catheter and potentially on the stent as well.

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Next-generation balloon catheters & stents

Stretchable electronic materials can be incorporated into or be direct structural elements of balloon catheters. Utilizing these active materials will allow local deployment of enhanced diagnostic and therapeutic capabilities at a defined cardiovascular anatomic...
Multifunctional balloon catheters of the future

These materials afford the potential to convert catheter systems from largely passive or manually activated systems to active, digital, smart systems. Recent proof-of-principle of this concept was demonstrated in a series of studies performed by our group [3,4]. As a first step, mechanical strain and force sensors, electrical conductance sensors and temperature sensors were incorporated on an expandable balloon catheter for electrophysiologic mapping and ablation. While initially envisioned for an electrophysiologic application, this demonstration has crossover to interventional cardiology. This study demonstrated the ability to decorate the surface of a catheter expandable balloon with a myriad of microelectronic devices that could provide digital high fidelity, high sensitivity accurate information about the arterial local microenvironment. Similarly, these systems may be incorporated onto the backbone of stents. We have previously described intelligent stents incorporating microelectronic systems for the detection of local pressure, mass or analyte changes that occur within or around the stent that may benefit from stretchable electronics [101].

The more information we can bring to bear on the diagnosis, localized treatment and post-treatment monitoring of endovascular therapeutics, the better we will likely be as far as enhancing long-term interventional treatment efficacy. Presently, we live in an era of ‘see, dilate and pray.’ Incorporating enhanced diagnostics, sensing and monitoring may finally get us into the domain of ‘see, interrogate and understand (know), treat and be confident.’ Stretchable polymeric-nanoelectronic composites provide the basis to drive this vision. The limits of this vision at this point remain only those of the imagination.

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Bibliography


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