Not since Osler have such powerful currents of change been evident in biomedicine. As the scale of the biomedical enterprise has grown to represent some 20% of the US economy, so the pressures to remodel almost every facet of the so-called medical-industrial complex have become irresistible. New contributors to the discipline and accelerating technological innovations will affect biomedicine in predictable and unpredictable ways, but the radical pace of some of the evolving change is already making the future more uncertain for the field than at any time since the postwar era. Although financial exigencies are driving the entry of many nontraditional participants into the biomedical arena, several other global scientific and secular trends are contributing importantly to the sense of imminent transformation.

The enthusiasm for molecular medicine that began almost 20 years ago as disease genes were cloned, combined with the new mechanistic insights that this effort spurred, is finally being applied to the clinical arena. Early successes in the diagnosis and therapy of cancer and the rapid commoditization of sequencing and other technologies are illuminating strategies to bring similar transformation to nonclonal chronic disease. There have also been remarkable developments in many other areas of fundamental and translational science. For example, the discovery of cellular reprogramming to pluripotency and the feasibility of recreating in vitro from patient-derived samples all the cell autonomous components of disease have opened new approaches to mechanistic modeling and drug discovery. The ease of generating recombinant proteins, humanized monoclonal antibodies, and stable forms of the full repertoire of RNAs has revolutionized our ability to manipulate disease pathways therapeutically, whereas gene editing technologies also promise to affect every field. The translation of numerous other innovations, such as nanotechnology or single-cell analysis, is imminent, but perhaps the largest impact will come from the long overdue penetration of technology or single-cell analysis, is imminent, but perhaps the largest impact will come from the long overdue penetration of computation and quantitative biology into medicine. The possibility that all extant information will be continuously collated, curated, and integrated then validated, bringing formal analytics to medicine, is clear, but there is also momentum for more radical change.

With mounting costs, society as a whole has begun to take seriously the need for improved efficiency in health care. There has been, through meaningful use in the United States, a progressive increase in the meager amount of information available on healthcare system performance. Yet, without dramatic improvements in the resolution of how we measure what we do, and without building systems that make these data available in real time, it will be difficult to effect real change. Part of the problem is the remarkable lack of standardization across medicine. The introduction of rigorous protocols for routine care might not only reduce variations in practice, but would also enable formal computation, permit the early identification of outliers, and lay the foundation for a learning digital health record. Real-time feedback could also stimulate completely different levels of precision in medicine, such as reimbursement based on evidence of efficacy in the individual patient.

Similar rationalization appears likely in the way that physicians collect other data types. Because genetics and other research areas identify low-resolution traits as one fundamental block in biomedical translation, it is becoming more obvious that comprehensive reappraisal of what data we collect as physicians will be required to leverage the power of modern informatics. Traditional binary phenotypes, largely refinements of 18th century observations, must be replaced by quantitative metrics of diverse physiological and cell biological traits. Standardized data acquisition protocols, a feature of randomized, controlled trials for decades, may finally be implemented in clinical practice. All this clinical care innovation implies the need for new data collection and data display infrastructure and the ability to integrate in the clinic, or at the bedside, the massive amounts of data accumulating in health care. Emerging technology will have to permit this bidirectional data flow without onerous data entry, and without the need to duplicate the informatics infrastructure for research.

Not only are the mechanics of medicine in flux, but the sociology of biomedical science is also undergoing a sea change. Traditional medical research or clinical care teams have been built around the individual investigator or individual clinician-patient relationship, respectively, but the teams of the future will be built with very different architecture. A major challenge will be to preserve the very best elements of the personal therapeutic relationship, while creating venues where new teams and new partnerships can evolve. For example, technology companies bringing new wearable sensors to market are teaming up with large pharmaceutical companies eager to segment their trial cohorts. Traditional payers are developing collaborations with big data companies to try to understand population health, although, in most instances, even our best current data sets may simply not be big enough to...
do so meaningfully. Surgeons and interventionists are conspiring to create less invasive ways to treat valvular heart disease with the eventual goal of eliminating conventional valvular surgery itself. This drive to make current approaches obsolete is a mantra in many innovative industries, yet the traditional rituals and constraints of modern medicine have slowed major changes in our field, decades after the same rationalizing forces remodeled other monopolies from the music industry to the legal profession. By defining more clearly which traditions in medicine are truly valuable, we must find ways to build systems that can reinforce and enrich these qualities while still allowing creativity and dynamism to flourish.

The transformation of medicine outlined here is likely just the beginning of a true revolution. The natural history of information technology has been to broaden information access and, in turn, to globalize previously local endeavors. In biomedicine, these trends will directly affect everything we do. Management algorithms for basic medical decision making will likely move to the individual patient, whereas stepwise improvements in information flow and simple convenience will begin to bypass traditional venues of medical care for all but catastrophic events. Many patients already perceive the medical establishment to be part of the problem, and our failure to deal with acknowledged issues such as heterogeneity of care delivery, lack of transparency, and chronic overstatement in research does nothing to mitigate this perception. That informed individuals are becoming more engaged in areas that previously were the provenance of the professional presents an immense opportunity, but also substantial threats to the monopolies of old. In an era where everyone will have the same information, biomedicine will have to consider where we truly add value and create a transparent reward system around that value. The old order dependence on cross-subsidization from procedural revenue is not likely to be sustainable, and the importance of cognitive input will have to be recognized.

To imagine even a fraction of this future becoming a reality without changing the culture of medicine is not easy, yet the die is cast. Although it is a testament to the power of deeply vested interests that biomedicine is the last sector of our lives to yield to such transformation, medicine also has a remarkable record of innovative change. To ensure that the biomedical professions are able to participate fully, medical education must undergo a parallel transformation. The best and the brightest must be attracted back to medicine. Quantitative skills systematically underrepresented in medical schools must be reemphasized. It will be important to rethink how we differentiate as individual professionals, acquiring new skills and reimagining adaptable teams of clinicians, translational investigators, and basic scientists. Retaining the best elements of the apprenticeship structure, while teaching physicians, scientists, and physician-scientists how to manage an exponentially growing knowledge base will require completely new tools and working structures. The tensions inherent in these challenges are already seen in the recent debate on Maintenance of Certification. Here, too, technology will play an important role, but in the context of much broader cultural change.

Role of Cardiovascular Biomedicine in Transformation Biomedicine

For many reasons, cardiovascular biomedicine finds itself at the leading edge of the transformation that is taking place. Cardiology has been at the forefront of many of the major movements within biomedicine, including wellness, prevention, randomized, controlled trials, guidelines, and scoring systems. There is a long history of engineering and in silico modeling in cardiovascular science, and the implantation and management of devices is already a core function of our specialty. As genomics, technology, big data, and other innovations are applied increasingly to common complex disease, cardiovascular scientists and clinicians will be among the leading exponents, whereas the pressures to redesign clinical care may be most acute in the cardiovascular arena. In this context, as the Circulation baton passes to our colleagues in Dallas, the current editorial team will over the next few months offer a vision for The Future of Cardiovascular Biomedicine in a series of reviews from each of the major areas of our field. The goal of this series is to bring our individual perspectives on how the next few years might play out in each area of endeavor within cardiovascular biomedicine. In some areas, the future is quite clearly mapped out, but in others there is little concrete information to guide us. We hope that these articles will pique interest and stimulate discussion in our pages and beyond as our community begins to realign itself for the remarkable decades ahead.

Disclosures

None.

Key Words: cardiovascular diseases • genomics • patient outcome assessment • physiopathology • prevention & control