Emerging Technologies in Surgery

With 90 Figures and 2 Tables
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Dedication

To our devoted wives,
Judith Satava, Franca Gaspari, and Fabiola di Lorenzo,
without whose encouragement and patience this would not have been possible.

During times of worry and frustration, you were there to console,
advise, and help us.

But most of all, you were our Muses, and gave us that unique inspiration
that lifts the mundane to the sublime.

For us, it was having you there to add that special sense of the aesthetic
that has made this monograph a true labor of love.
We live in a technological age, and the practice of surgery is not exempt from this. Furthermore, predictions are that the inevitable trend in surgical practice is toward increasing dependence on high-technology equipment. Thus, Emerging Technologies in Surgery edited by Richard Satava, Achille Gaspari, and Nicola Di Lorenzo, is timely and appropriate. My experience with use of medical technologies together with my involvement in related research and development work over many years has led me to classify these technologies in four categories all expertly covered in this book: (1) facilitative—improve the efficiency of performance and reduce the degree of difficulty of execution of specific tasks; (2) additive—bring technical sophistication and accuracy to surgical manipulations/interventions that are not considered essential to existing practice; (3) enabling—make possible certain surgical interventions or open new therapeutic approaches; and (4) disruptive—technologies that, by breaking new ground, underpin real progress. The term “disruptive technologies” was first coined by Clayton M. Christensen in 1997 in his book The Innovator’s Dilemma (Harvard Business School Press), to refer to technologies that, as they mature, alter the way humans live and work.

Wisely, the three editors of this book, rather than pigeonholing the technologies covered in this excellent monograph, have adopted a different layout more suited—from a practical and educational standpoint—to the current and future practice of surgery; however, examples of all these categories are included in the various sections. The contributions to all these sections are by leading-edge experts in the respective fields, and after reading all the chapters, I have no doubts that the editors chose their contributors wisely. Emerging Technologies in Surgery should be of interest to both the surgical trainees and their trainers, because it contains a wealth of useful and practical information on the subject. It is appropriate in my view that emphasis has been made on education and training, as they are axiomatic to quality care in surgical practice. The advances in virtual surgical simulation that, after a shaky start, have in the last few years progressed to a stage where no surgical training program can afford to overlook their importance; the apprenticeship system of training is no longer sufficient, especially with the curtailment of the training period. The World Wide Web and progress in medical informatics in general (disruptive technologies in the extreme) have removed all possible excuses for all healthcare providers—let alone surgeons—to be misinformed or be lacking in medical up-to-date information, because the technology brings accurate information to the shop floor of medical practice. There is, however, one issue directly related to the increasing dependence of surgical care on high technology that I feel has been overlooked in all training programs and which needs emphasis: Surgeons and other interventionalists increasingly use sophisticated energized equipment often and regretfully, without an adequate understanding of the physical and engineering principles involved. This cognitive deficit of current training program needs correction.

It seems to me that the approaches covered in the various sections of Emerging Technologies in Surgery are breaking down turf barriers between disciplines, such that patient management is slowly changing from isolated, single-discipline treatment to multidisciplinary treatment by disease-related treatment groups, which surgeons must buy into. The spate of integrations, witnessed on both sides of the Atlantic between vascular surgeons and interventional vascular radiologists over the past 5 years, is a pertinent example.

The editors are to be congratulated for an immensely readable and informative monograph. It deserves to be read and will, I am sure, be well received. I suspect, however, that we shall witness several future editions since one thing is sure: Medical technology does not stand still … for long.

Sir Alfred Cuschieri, FRS
Professor of Surgery
Pisa
Tremendous acceleration and changes in our daily medical practice are occurring. Both as doctors and ordinary citizens, we are aware of living in a world more and more influenced by information technology. In surgery, this revolution has brought about a dramatic acceleration of the introduction of new devices, techniques, and procedures that are changing patients’ treatment and destiny. In the last 30 years, innovation has developed exponentially, forcing both current and future generations to deal with new technologies such as microsurgery or laparoscopy, and informatics. Meanwhile, the old surgical approach still needs to be learned and mastered for patients’ safety.

Therefore, we decided to offer this book to illustrate to the practicing surgeon, who has precious little time to keep up with these rapid changes, what the important emerging technologies are that could affect his or her practice in the next 10–20 years. We approached this effort with the expectation that this book will serve as a useful reference to introduce surgeons of every generation to the principles of new technologies, and to familiarize them with those new procedures and devices that seem to belong to the future but in reality are being implemented now. Because time and resources are not infinite for the surgeon, both in everyday life and in their busy practice, we hope this monograph will contribute to their ability to select those innovations that will positively impact on his or her practice.

To that end, we have invited eminent surgeons who are experts on emerging procedures and significant advances in their respective fields to participate. We have been fortunate to assemble authors who are acknowledged authorities in these areas, both in clinical practice as well as in surgical education. We are grateful to them for their essential contributions, to bring together, outline, and illustrate the future trends. We are especially indebted to Dr. Manzelli for his invaluable support during the preparation of this work. We are proud to have the privilege to stand on the shoulders of these giants.

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Part I

Introduction
Around 20 years ago, few had been able to imagine the future of surgery. Scientific progress and potentiality are amazing, and the next century will proceed in a radical new approach towards the practice of medicine. It will be based on information technology, defined as the devices that acquire information; those that process, transmit, and distribute information, and those that use information to provide therapy. Although conventional surgery will continue to have a presence, there will be radically different surgical approaches and technologies that may become the predominant form of surgery [1]. The field of surgery is entering a time of great change, spurred on by remarkable recent advances in surgical and computer technology. Surgical robotics is on the cusp of revolutionizing evolution of the new technologies. The last decades have seen robots appearing in the operative room worldwide. Thanks to its advancement, robot technology is now regularly used in endoscopic surgery and, in general terms, in minimally invasive surgery. It is still hard to believe that the future of robotics surgery is now. The use of robots has assumed a principle role in main surgical procedures in chief medical referral centers in Western countries. It is used widely for many minimally invasive procedures including Nissen fundoplication for treatment of gastroesophageal reflux disease, radical prostatectomy, hysterectomy, donor nephrectomy for kidney transplant, and reconstruction of the kidney and ureter, producing safe and notable results with benefit for patients: smaller incisions, less injury to surrounding tissues, lower risk for wound infection, shorter hospitalizations, and quicker recoveries [2–4].

One reason surgical applications are progressing quickly is the large technology base that has been developed in robotics research in the past three decades [5]. Results in mechanical design, kinematics, control algorithms, and programming that were developed for industrial robots are directly applicable to many surgical applications. Robotics researchers have also worked to enhance robotic capabilities through adaptability (the use of sensory information to respond to changing conditions) and autonomy (the ability to carry out tasks without human supervision). The resulting sensing and interpretation techniques that are proving useful in surgery include methods for image processing, spatial reasoning and planning, and real-time sensing and control [6]. In surgery, the robotics system enhances the surgeon’s precision and capabilities in laparoscopic procedures, which are performed through tiny incisions with pencil-thin instruments and cameras. The robot moves high-speed cutting tools to perform precise incisions and safe dissection, and the system provides the surgeon a three-dimensional imaging of the operating field, giving intuitive hand movement, resulting in significant improvements over standard laparoscopic surgery. We must not forget that traditional laparoscopic surgery has two-dimensional imaging, and the movement of instruments is “counterintuitive”, i.e., similar to doing surgery while looking into a mirror [7].

Robotic surgical systems provide the surgeon with nearly all of the natural movements of the human wrist. They also eliminate natural hand tremors and improve dexterity to enable surgeons to do ever-finer surgery in a more controlled manner [8].

However, humans still are superior at integrating diverse sources of information, using qualitative information and exercising judgment. Humans have unexcelled dexterity and hand–eye coordination, as well as a finely developed sense of touch. Unlike interaction with robots, interaction with human members of a surgical team for instruction and explanation is straightforward. These differences in capabilities mean that current robots are restricted to simple procedures, and humans must provide detailed commands, using preoperative planning systems or by providing explicit move-by-move instructions. Even in the most sophisticated systems, robots are specialized to specific tasks within procedures; humans must prepare the patient, make many of the incisions and sutures, and perform many other functions. Robotic systems are best described as “extending human capabilities” rather than “replacing human surgeons”.

In fact, what we today call robot is in reality an effector, a material performer, a transducer of a commands that are directly imparted by the human being that checks and directs closely the sensibility, the move-
ment, and in practice therefore the action. Nevertheless, in the common imaginary the robot replaces the human being in the working assignments not as ungrateful persons, perfectly adherent to the etymology of the Czech term \textit{robota}, or “servitude” or “forced labor”. Therefore, the trick to imagining the future of surgery is really to think of robots as animated, i.e., an operator and worker endowed with artificial intelligence and founded on the development of complex neural networks to the service of human beings through a truth and height remote control.

Medicine of the future and progresses in new technologies applied to surgery is not only concept of robotics systems and their application in operating room of the future, but also diffusion of knowledge, sharing of ideas, standardization of the procedures, scientific competences of sectors, standardization of the therapies, professional and formative education that, translated in different terms, produce qualitative improvement of healthcare systems worldwide. The scenario of the world of surgery is already changing, passing from the structural organizations to reach the arena of the teaching and the future of new generations of the surgeons.

The introduction on minimally invasive surgery has demonstrated the need for training surgical skills outside the operating room, using animal model or simulators. As laparoscopic surgery involves displaying images on a screen, virtual reality simulation of surgical task is feasible. Different types of simulators have become available. All simulators aim at training psychomotor skills, and some simulators also allow training in decision making and anatomical orientation. In the near future virtual reality simulators may become a tool for training and validation of surgical skills and monitoring the training progress [9].

Another field of application of the complex world of advancement in scientific technical progress is the access and the fruition of communication. Widely present in the normal daily life of everyone—especially in Western countries—the new means and modalities of communication and information technologies have significantly revolutionized access to surgical education. The introduction of the Internet information highway into mainstream clinical practice as an information-sharing medium offers a wide range of opportunities to healthcare professional. An amazing example of a world virtual university is WebSurg.com, dedicated to minimally invasive surgery laparoscopic surgery updating and professional education, assuring contributions to the worldwide diffusion of scientific information in an easy and user-friendly way. [10].

The exponential growth in information technology is resulting in a rapid increase in the ability to develop useful applications on the Internet. It is becoming difficult for surgeons to reach their full potential unless they exploit Internet-based activities. This is because the ability to rapidly capture information of quality is an essential ingredient in a reflective approach to surgical problems. More futuristic is the prospect of using computer-based technology to operate on patients from a distance, as proposed by telesurgery. With the advent of laparoscopic surgery, a method characterized by a surgeon’s lack of direct contact with the patient’s organs and tissue and the availability of magnified video images, it has become possible to incorporate computer and robotic technologies into surgical procedures. Computer technology has the ability to enhance, compress, and transmit video signals and other information over long distances. These technical advances have had a profound effect on surgical procedures and on the surgeons themselves because they are changing the way surgery is taught [11].

Finally, a mention of telementoring. It is used when an experienced surgeon assists or directs another less experienced surgeon who is operating at a distance. Two- and three-dimensional, video-based laparoscopic procedures are an ideal platform for real-time transmission and thus for applying telementoring to surgery. The images viewed by the operating surgeon can easily be transmitted to a central “telesurgical mentor” and permit intraoperative interaction. Several studies have demonstrated the practicality, effectiveness, and safety of surgical telementoring. The goal of this application of telemedicine is to improve surgical education and training, expand patient care, and improve healthcare delivery by allowing access to surgical specialists. Eventually, surgical telementoring could assist in the provision of surgical care to underserved areas, and potentially facilitate the teaching of advanced surgical skills worldwide [12].

What future awaits us? Will surgeons be able to follow the entire and complex world of scientific progresses? Are surgeon of tomorrow ready to be abreast of the increase of knowledge and request of quality of assistance? Modern surgery is relatively young, and despite this it has a history noble, and illustrious sort of audacity, rush and grandiose, and perspective vision of the future. The exponential growth of unknown affairs is still intimately tied to the nature of man and the drive to attain knowledge. The future requires preparation and attention to understanding of the knowledge necessary in the exclusive direction of the interest of humanity, improving performances, increasing quality solutions, providing availability of the scientific competences of sector, standardizing procedures, and providing worldwide formative education.
References

2.1 Technology: A Definition of Terms

Technology is that body of knowledge available to a civilization that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials [1]. It is the science that concerns itself with the application of knowledge to practical purposes. Others have suggested that the characterization of technology be expanded to include those technologies that sustain the way a thing is done or performed, and those technologies that change the way things are accomplished [2]. In this sense, sustaining technologies are those technologies that keep up or improve the status quo but do not disrupt or create chaos in existing situations. New growth is not fostered. On the other hand, disruptive technologies are those technologies that create major new growth in areas they penetrate and disrupt or cause to fail the entrenched technologies. New growth can occur because less skilled persons are enabled to do things previously done only by expensive specialists in centralize (typically inconvenient) locations. The consumer is offered services or products that are cheaper, better, and more convenient than previously provided.

2.2 A Brief History of Medical Technology

Surgical technology and the skills to practice operative intervention were essentially embryonic for the first several thousand years of recorded history. The overwhelming and intense pain associated with surgery limited operative procedures to only those that were simple and rapid. In addition, there was limited knowledge of the role of bacteria in the development of infection. Wound contamination was common, and sepsis frequently resulted in death of the surgical patient.

The discovery of anesthesia and the acceptance of antisepsis stimulated the development of surgical instrumentation during the late 19th century. Growth, nevertheless, was slow, and technological innovation was essentially a sustaining one as clamps, retractors, scalpels, and other devices developed before or during the 19th century were refined, but little changed. Creative surgical innovators focused on ways to extirpate or correct disease processes, and new, innovative operative procedures were developed. However, the technology utilized to perform these operations remained unchanged. And remained so for almost a century. In a similar vein, costs for surgical instruments (technology) remained stable and relatively predictable.

During the latter part of the 20th and the beginning of the 21st century, however, surgery became a technology-driven profession. There was a disruption of the status quo. The development of new technologies (energy sources, mechanical devices, imaging, etc.) ultimately led to a radical change in how surgery was practiced. Spectacular medical achievements were due to advances in technology that in many instances was disruptive of the status quo. These technological advances enabled physicians to diagnose and treat disease more accurately than before. Computerized tomography (CT), magnetic resonance imaging (MRI), and diagnostic radioisotope studies revolutionized the field of radiology. Portable, affordable ultrasound units gave the gynecologist an office-based tool to accurately and conveniently diagnose female genital tract disease. Minimally invasive surgery (a stunning example of the combination of several disruptive technologies) combined solid-state cameras, high-resolution video monitors, and laparoscopes to completely change the way physicians exposed and managed surgical disease. No longer was a large traumatic surgical incision required to visualize intracavitary organs.

Present-day technologies have allowed clinicians to gather more information and refine differential diagnosis prior to operative intervention. CT scans and diagnostic laparoscopies in many instances have replaced the need for exploratory laparotomy. The result has been a decrease in patient risk and morbidity. New technologies have not only enhanced quality of life, but also in many instances, extended it.
2.3 The Economic Burden of Health Care

Men and women throughout the world and particularly in developed Western countries have come to expect, indeed to demand, high-technology health care. The advances in technology and medical devices, however, have come at a very high price and have generated wrenching ethical and social debates. National health expenditure in the United States, for example, increased from $41.0 billion, or 5.7% of the gross domestic product (GDP) in 1965, to $1,299.5 billion in 2000, or 13.2% of the GDP. National health care expenditure on a per capita basis increased from $205 in 1965 to $4,672 in 2000 [3]. Health care spending continued to rise in the United States, reaching $1.4 trillion in 2001. This was an 8.7% increase from the year 2000. Health care spending increased three times faster than did growth of the US economy. In the year 2000, health care spending was $4,672 per person, which increased to $5,035 per person in 2001 [4].

The number of medical schools in the United States increased from 86 in 1960 to 126 in 1994, and the number of medical students increased from 30,288 in 1960 to 66,629 in 1994. There were 5,407 hospitals in the United States in 1960, with 639,000 beds, and 5,321 hospitals, with 923,000 beds in 1992. Only a modest increase of hospital beds, but on the other hand, the number of freestanding ambulatory surgical centers increased from 459 in 1985 (783,864 procedures performed) to 1,862 in 1993 (3,197,956 procedures performed) [5]. The US population in 1960 was 179,323,175 people, and by the year 2001 increased to 284,796,887. Most could afford health care. As reported by the US Census Bureau in 2001, the number of persons with health insurance was 240.9 million; the number of uninsured persons was 41.2 million [6].

The increase in health care demand and supply has not been confined to the United States. All major developed countries have experienced a similar increase. For example, health care expenditures in the United Kingdom increased as a percentage of gross domestic product from 4.5% in 1970 to 7.1% in 1992. Viewed another way, this translated to health care spending per capita increase in the United Kingdom from $146 in 1970 to $1,213 in 1993. Similarly, health care spending as a percentage of gross national product in France increased from 5.8% in 1970 to 9.4% in 1992. On a per capita basis, French health care spending increased from $192 in 1970 to $1,835 in 1993. Countries in the Far East have not been exempt from this trend and in Japan, the percentage of expenditures on health care as related to gross domestic product increased from 4.4% in 1970 to 6.9% in 1992. Put another way, health care spending per capita in Japan increased from $126 in 1970 to $1,495 in 1993 [5].

The demand for health care has been fueled in part by readily available worldwide communication. Nearly universal access to mass communication, radio, television, and the Internet has educated consumers and has helped create a demand for cutting-edge care. A consensus appears to be developing that people of the world are beginning to expect certain rights of their governments including respect of person, dignity, and access to health care. Because of this public demand for health care, a major issue undergoing debate in various countries has been whether a society or a nation should restrain advances in expensive health care technology or attempt to fulfill the universal human desire for good health regardless of cost. Many believe that no one should be denied access to health care because of cost, but few deny the overwhelming importance of prudent economic management in the delivery of health care.

Costs for health care have unrelentingly spiraled upward, and there appears to be no end to the increasing financial burden on individuals, societies, and states. Demand has outstripped supply. As a benchmark, it is worth noting that the average US general surgeon performed 398 procedures per year from 1995 to 1997. Of these cases, 102 (26%) were abdominal procedures, 63 (16%) were for alimentary tract procedures, 55 (14%) were for breast operations, 51 (13%) were for endoscopic procedures, 48 (12%) cases involved soft-tissue operations, 39 (12%) cases were vascular procedures, trauma accounted for 6 (2%) cases, 4 (1%) cases were for endocrine disease, and 3 (1%) were for head and neck. Of the 398 procedures, 44 (11%) cases were for minimally invasive laparoscopic operations [7]. This is an average yearly workload for a general surgeon in the United States, and may be taken as a baseline for what a general surgeon can accomplish in a developed Western country that has a high demand for health care.

2.4 A Technological Solution to Health Care Cost

In many poorer countries, the ability (financial remuneration, personal growth, safety, quality of life issues, academic satisfaction, etc.) to supply and deliver health care is very limited or nonexistent. The solution to the dilemma of providing health care in an environment of limited resources has been obscure, but with the use of disruptive technologies, the solution may be obtainable.

Over the last 50 years, technology has revolutionized health care, and it will likely continue to do so in the future. Technology, however, comes in many guises. It is in the application of technology and, in particular,