Dramatic innovations in modern surgical subspecialties

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Innovation is defined as the introduction of something new, whether an idea, method or device. In this article, we describe the most important and innovative concepts and techniques that have advanced patient care within modern surgical subspecialties. We performed a systematic literature review and consulted academic subspecialty experts to evaluate recent changes in practice. The identified innovations included reduced blood loss and improved training in hepatobiliary surgery, total mesorectal excision and neoadjuvant therapies in colorectal surgery, prosthetic mesh in outpatient surgery, sentinel lymph node theory in surgical oncology, endovascular and wire-based skills in vascular and cardiovascular surgery, and the acceptance of abnormal anatomy through damage-control procedures in trauma and critical care. The common denominator among all subspecialties is an improvement in patient care manifested as a decrease in morbidity and mortality. Surgeons must continue to pursue innovative thinking, technological advances, improved training and systematic research.

L'innovation s'entend de l'avènement d'une nouveauté, qu'il s'agisse d'une idée, d'une méthode ou d'un dispositif. Dans cet article, nous décrivons les concepts et les techniques les plus importants et innovateurs qui ont fait progresser le soin des patients, dans le contexte des surspécialités de la chirurgie moderne. Nous avons effectué une recension systématique des écrits et consulté des experts des surspécialités universitaires afin d'évaluer les changements récents de la pratique. Les innovations décrites incluaient une diminution de la perte de sang et une amélioration de la formation en chirurgie hépatobiliaire, l'excision mésorectale totale et les thérapies néoadjuvantes en chirurgie colorectale, l'usage de la résille prothétique en chirurgie externe, la théorie du ganglion lymphatique sentinelle en oncologie chirurgicale, les techniques endovasculaires et électroniques de chirurgie vasculaire et cardiovasculaire, ainsi que l'acceptation de l'anatomie anormale par des interventions visant à limiter les dégâts en traumatologie et en soins intensifs. Le dénominateur commun entre toutes les surspécialités réside dans une amélioration du soin des patients démontrée par une diminution des taux de morbidité et de mortalité. Les chirurgiens doivent continuer à diriger leurs efforts vers la réflexion novatrice, les progrès technologiques, l'amélioration de la formation et la recherche systématique.

Innovation is defined as the introduction of something new, whether an idea, method or device.[1] In the modern surgical era, this process ideally occurs via a graduated system of original thinking, surgical ingenuity and rigorous research. Whereas the best of these innovations have the potential to incite major shifts in paradigm (change the basic assumptions within the ruling theory of science[2]), most do not achieve this end point. Although they may not attract the same attention as true paradigm shifts (i.e., the introduction of anesthesia, antisepsis techniques and medications, organ transplantation, laparoscopy), these other innovations are vitally important in the evolution of each surgical subspecialty.

The absolute number of peer-reviewed publications specific to a new innovation is often considered an indicator of its relative contribution. Unfortunately, quantitative analysis is not always the most precise method of identifying the techniques or concepts that result in important evolutionary steps within surgical subspecialties. As a result, we used a combination of literature reviews, as well as extensive discussions with subspecialty academic surgeons about the modern innovations that have most significantly impacted their current practice of hepatobiliary, colorectal, outpatient, surgical oncology, vascular, cardiovascular, trauma and critical care surgery.

HEPATOBILIARY SURGERY

Resective hepatobiliary (HPB) surgery was undertaken very infrequently and often with great trepidation in the 1960s and '70s. A collective multi-institutional review by Foster and Berman[3] in 1977 outlined a 20% perioperative mortality rate for all major resections. Twenty percent of these deaths were a direct result of massive hemorrhage. As a consequence of the rich vascularity of the liver (dual inflow via the portal vein and hepatic artery with venous outflow via the hepatic veins), bleeding has always been the major problem encountered during resective liver surgery. Blood loss during hepatectomy results in numerous difficulties, including reduced visualization of key structures, increased transfusion of blood products and organ failure leading to death. Allogenic blood transfusions are also immunosuppressive and may increase both short- and long-term morbidity and mortality and the risk of cancer recurrence.[4–7]

Improvements in outcomes following hepatic surgery are the result of many factors, including better patient selection, anesthesia modifications, refined operative techniques, a more thorough understanding of hepatic anatomy, increased use of parenchymal-sparing resections and improved preparation of the future remnant liver using preoperative portal vein embolization and/or biliary decompression in patients with jaundice. The formation of HPB surgery as a defined area of subspecialization within general surgery,[8–10] coupled with a plethora of evidence over the past decade that hepatic and pancreatic surgery are some of the most sensitive operations to the volume–outcome relation,[11–14] represent the primary reasons that HPB surgery is now largely performed in high volumes at specialized centres.[8,10] As a consequence, surgeons currently receive training in HPB surgery via structured fellowships (surgical oncology, HPB, liver transplantation, upper gastrointestinal), as opposed to being self-taught, as was the case for most operators performing hepatic and pancreatic surgery the 1970s and '80s.

The 2 primary factors that have minimized operative blood loss during hepatectomy are the implementation of a low operating central venous pressure (CVP) and the judicious use of appropriate hepatic inflow and outflow occlusion.[11,15–19] These techniques have allowed surgeons to perform complex liver resections with minimal blood loss. Inflow occlusion (Pringle manoeuvre) to the liver results in the complete arrest of bleeding from branches of the portal vein and hepatic artery. The cost of inflow occlusion is ischemic insult suffered by the liver and a concomitant increase in the risk of postoperative hepatic insufficiency.[20–22] Outflow occlusion, or total vascular exclusion, is used to control all blood flow into and out of the liver.[23] In general, intermittent inflow occlusion, or the use of ischemic preconditioning,[24] is a safe technique to decrease operative blood loss. Total vascular exclusion should be reserved for patients with large deep tumours abutting the hepatic veins and patients with elevated CVPs. The use of a low CVP significantly decreases blood loss from injuries to the very fragile hepatic veins during parenchymal transaction. The judicious use of inflow occlusion in conjunction with a low operating CVP has revolutionized the safety of hepatic resections.

Major HPB surgery now results in mortality rates below 5%,[11–14] and complicated multivisceral resections can be performed with acceptable morbidity and mortality in selected patients.[25]

COLORECTAL SURGERY

As the sentinel disease in colorectal surgery, rectal cancer has undergone the most significant change in management within this subspecialty. This includes both the widespread adoption of total mesorectal excision (TME) as the standard of care as well as the use of neoadjuvant chemoradiation for locally advanced disease.

Total mesorectal excision involves careful dissection in the areolar tissue outside the fascia propria of the rectum and mesorectum while preserving the hypogastric nerves (sympathetic) and nervi erigentes (parasympathetic).[26] This technique is generally reserved for lesions of the mid and distal rectum, because more proximal lesions typically undergo a resection of the mesorectum for a length of 5 cm beyond the tumour. Although this technique was practised by numerous surgeons before 1982, it was widely popularized by Heald,[26–28] who reported a very low recurrence rate using TME alone in the treatment of rectal cancer. Heald then spent considerable time and effort to help establish its widespread adoption.[29,30] This work was the impetus for many surgeons to adopt the principles of TME into the care of their own patients. As a consequence, TME has resulted in a significantly reduced rate of rectal cancer local recurrence. More specifically, comparisons of standard and TME surgery have shown a decrease in local recurrence from 14%–39% with standard surgery to 4%–10% with TME.[31,32]

Whereas adjuvant radiation and chemotherapy have improved outcomes in the treatment of locally advanced rectal cancer, recent studies have also shown advantages of neoadjuvant therapy. When combined with traditional non-TME surgery, preoperative radiation decreases local recurrence from 21%–46% to 11%–36%.[33–35] The Dutch Rectal Cancer Trial found that the addition of preoperative short-course radiation to TME decreased local recurrence from 10.9% to 5.6%.[36] The German Rectal Cancer Study also recognized the importance of preoperative long-course chemoradiation (local recurrence rates of 6% in the preoperative treatment cohort v. 13% in the postoperative group).[37] Finally, early unpublished results from the Medical Research Council–CR07 trial (MRC-CR07) comparing short-course preoperative radiation to selective postoperative chemoradiation again showed a decrease in the 3-year local recurrence (4.7% in the preoperative arm v. 11.1% in the postoperative group).[38] As a consequence, the use of neoadjuvant radiation or chemoradiation in addition to TME as the standard surgical approach in patients with stage 2 or 3 rectal cancer has resulted in a quantum leap forward in the management of rectal cancer.

Outpatient surgery

Although the very concept of dividing "general surgery" into smaller subspecialty units can be considered a surgical innovation, inguinal hernia repair remains the most common operation performed worldwide by the general surgery community. The evolution of this procedure is rich in history, and its innovators include many of the most significant names in surgery. Almost 100 years ago, Bassini's description of an anterior repair using primary tissue closure of the hernia defect laid the groundwork for future surgeons to refine.[39] Despite many of these advances, the recurrence rate for an inguinal hernia repair remained at about 10%.[40]

Over the past 15 years, however, the introduction of implantable prostheses has forced a fundamental change in the way this disease is approached. Popularized by the work of Lichtenstein in the early 1990s, mesh implantation addressed both major problems with primary tissue repairs: first, tension was removed from the suture line, and second, collagen-poor primary tissue was no longer the strength-containing layer. Lichtenstein's modifications revolutionized the management of inguinal hernia repair, with most general surgeons subsequently adopting some form of his procedure. This tension-free repair was easy to learn, suitable for multiple hernia types, allowed earlier return to normal patient function and had a recurrence rate of less than 1%.[41]

With the transition to tension-free mesh repair, a new set of procedure-related adverse effects has arisen. Postherniorrhaphy pain syndromes have become increasingly prevalent and difficult to manage.[42] The most feared potential complication following mesh implantation, however, is infection. Fortunately, the last 15 years have also seen several improvements in the prevention of surgical infection with the use of perioperative antibiotics. As a result, the infection rate is currently less than 2% in most series.[43]

The concept of tension-free hernia repair using an implantable prosthetic has recently been applied to herniae outside the inguinal canal. The current preferred method of managing ventral,[44] femoral,[45] spigelian,[46] hiatal[47] and obturator[48] hernias is with mesh. The development of component separation for repair of large ventral defects is also an extension of the tension-free repair, albeit without mesh. Finally, mesh implantation has allowed laparoscopic hernia repair to become a viable option.[49] These innovations have resulted in improved clinical outcomes including reductions in recurrence rates and postoperative pain levels, as well as an earlier return to normal activity.

Surgical oncology

Recent innovations in the field of surgical oncology include aggressive, multimodality and potentially curative treatment of stage 4 disease (abdominal pseudomyxoma or carcinomatosis from appendix and colorectal cancer[50,51]); minimally invasive surgery for intra-abdominal malignancies;[52] and neoadjuvant multimodality regimes to convert potentially unresectable, locally advanced disease (gastrointestinal stromal tumours) to resectable lesions (downstaging).[53,54] The most pervasive innovation in surgical oncology, however, has been the evolution from formal elective/staging lymphadenectomy for breast cancer and melanoma to sentinel lymph node biopsy (SLNB). Because breast cancer is the most common malignant disease among American women and melanoma has one of the highest increases in annual incidence rates,[55] this shift has had a tremendous epidemiologic impact. It is also particularly striking because it has occurred via a rationale approach to scientific inquiry that has included numerous level 1 multicentre randomized trials.

The sentinel lymph node (SLN) is considered the first site of lymphatic spread for malignant disease.[56] The SLN hypothesis states that the identification and analysis of the SLN for metastatic involvement should predict the status of the remaining regional lymph node basin. Because a large proportion of patients with breast cancer and melanoma do not have lymph node metastases, most patients receive no staging or therapeutic benefit from the removal of uninvolved nodes. Furthermore, associated morbidity as well as the difficulty for a pathologist to thoroughly focus on multiple nodes for tumour burden is not insignificant.[57] Following the development of blue dye and gamma probe radioactive tracer detection,[58,59] SLNB has been used with increasing frequency. A large meta-analysis found 69 trials with 8059 patients published between 1970 and 2003.[60]

In patients with breast cancer, the high accuracy and low rate of false-negative results with the SLNB has been confirmed in trial comparisons of various combinations of SLNB and axillary lymph node dissections (ALND).[61–63] Preliminary results from the National Surgical Adjuvant Breast and Bowel Project B-32 (NSABP B-32) trial also suggest that overall survival is similar.[62] Results from a large randomized trial of SLNB in malignant melanoma (Multicentre Selective Lymphadenectomy Trial-1 [MSLT-1]) had similar accuracies (95.3%).[64] Furthermore, the incidence of SLN involvement was 16% in 764 patients randomly assigned to the SLNB arm,[65] which compared with a clinical lymphatic recurrence of 15.6%

among the 500 patients in the observation arm. Finally, the 5-year survival rate was higher among patients with SLNB-positive disease treated by ALND compared with those who underwent delayed ALND at time of clinical recurrence in the observation arm.[65] Other multicentre trials are ongoing.

Sentinel lymph node biopsy has also met its goal of avoiding the major morbidity associated with standard axillary lymphadenectomy in breast cancer. Patients undergoing SLNB alone had less pain, numbness and lymphedema, as well as improved arm mobility compared with those in the ALND groups.[63,66] These patients also had significantly better scores in physical and mental function[66] and quality of life.[67] Most recently, a large multicentre trial reported adverse surgical effects in 25% of the SLNB group compared with 70% of those in the ALND group.[68] The Sunbelt melanoma trial (2564 patients) also found reduced rates of seroma, hematoma, lymphedema and overall complications with SLNB.[69]

In breast cancer, SLNB has nearly replaced routine axillary lymphadenectomy in clinically node-negative patients.[70] Despite caveats of minimal procedure volume thresholds before a surgeon should adopt SLNB alone, it is now in widespread use. Seventy-seven percent of all respondents to a random 2001 survey reported performing SLNB in patients with invasive breast cancer.[71] More recently, data from Cancer Surgery Alberta's operative database suggest that about 90% of breast cancer patients are being staged with SLNB.

The SLNB procedure has shifted the treatment of melanoma even more dramatically. It is part of the American Joint Committee on Cancer's cancer staging manual and leads to improved staging of patients with intermediate thickness melanoma.[72] As a result, elective lymphadenectomy for the staging and treatment of melanoma has essentially been abandoned.[73] Sentinel lymph node biopsy is also now being studied in virtually all solid malignancies with a risk of lymph node metastases (colon, vulvar, anal, merkel cell, head and neck).[57,74–78]

Vascular and cardiovascular surgery

Fundamental innovations in modern vascular surgery include the introduction of endovascular repair for abdominal aortic aneurysms (EVAR), management of peripheral vascular pathology with catheter-based techniques and training system modifications required to teach these radically new technologies. As a result, there is a growing consensus that vascular surgery should no longer be considered a subspecialty of general surgery but should instead involve an independent pathway to certification. With the advent of endovascular approaches as an option for the management of thoracic aneurysms (TEVAR), cardiac surgeons are now facing the same dilemma. Interest in TEVAR has also been stimulated by the development of percutaneous approaches to aortic and mitral valve replacement, as well as the decrease in coronary artery bypass procedures. This overlap calls into question the degree to which cardiac surgery will reintegrate with vascular training.

While it is clear that EVAR is now an accepted approach to managing abdominal aortic aneurysms (including ruptures) and that TEVAR is a viable alternative for treating both thoracic atherosclerotic aneurysms and emergencies (including traumatic aortic rupture and complicated acute descending dissection),[79–81] vascular surgery recognized the increasing role of catheter-based interventions relatively early. Over 15 years ago, independent skills were sought out not only to maintain relevance as a specialty but also to provide optimal patient care within a single setting.[82,83] In 2001, a marked reduction in open infrarenal repairs of abdominal aortic aneurysms over the preceding 5-year period was noted to have occurred concurrently with an increase in EVAR.[84] Between 2000 and 2005, a typical vascular fellow's experience in interventional procedures increased from 15 to more than 200, with nearly 50% of all procedures being interventional rather than open surgical reconstructions.[85] Concern about how to maintain adequate open surgical case volumes in the modern training environment is significant.[82] International endovascular requirements for achieving competence in certified training programs have recently been established.[86] The recommended case mixes should be equally divided among the 4 major vascular beds (aortoiliac/brachiocephalic, abdominal visceral and renal, infrainguinal, cerebral), and 5 catheter-directed peripheral thrombolytic/ectomy cases should be completed. There have also been specific recommendations for obtaining skills and certification among senior surgeons with extensive operative skills who did not have the opportunity to obtain interventional or endovascular training during their fellowships.[87]

As cardiac surgery evolves to embrace TEVAR, there has been an obvious diversion from their colleagues in cardiology, interventional radiology and vascular surgery. Cardiac surgery emphasizes the importance of operative skills, years of clinical experience in managing a wide variety of thoracic pathologies, and understanding the biology and natural history of thoracic aortic disease.[88] Although not completely dismissive of these factors, the other specialties place more emphasis on broad-based catheter skills. There is a growing number of cardiac surgeons who have embraced "complete" catheter and wire skill training to eliminate this potential for conflict.[89] Many training programs also now incorporate dedicated "cath-lab" time as part of an active aortic centre.

Trauma and critical care

Although the role of computed tomography and its subsequent impact on nonoperative therapy for solid organ injury undoubtedly represents a massive innovation, the use of the "damage control" philosophy among critically injured patients is also regarded as a revolutionary advance in the thought and practice of surgery.[90] Damage control describes a constellation of approaches to surgical problems that lie beyond immediate local capabilities and patient physiology. More specifically, this philosophy requires a staged approach to life-threatening surgical issues.[91,92] A damage control or "abbreviated" laparotomy constitutes hemorrhage control, prevention of enteric spillage and a ready acceptance of planned reoperations.[91,92] Because the procedure must be accomplished quickly to avoid exhausting the patient's physiologic reserve, it is resource-intensive and demands that the surgeon be sound in technique and judgment.

Despite the many potential techniques and devices that can be used in a damage-control scenario, the fundamental innovation is really the acceptance of abnormal anatomy (intraperitoneal packs, blind-ended bowel loops, prosthetic vascular shunts, open abdomen) in an attempt to preserve patient physiology.[93] The classic conduct of surgery is interrupted to prioritize physiologic rather than anatomic repair. Although this physiologic-focused repair phase is often conducted in the intensive care unit, it may also be performed in the operating room if necessary. At the highest level, this goal requires accepting an aberrant state to prevent iatrogenic harm and is therefore a modern day revitalization of the timeless injunction to all physicians: *primum non nocere*.[94,95] When viewed from this perspective, other critical care innovations, such as accepting hypercapnia in severe obstructive lung diseases and acute lung injury,[96,97] following a low hemoglobin level[98] and not rewarming patients with isolated severe head injuries (i.e., without truncal hemorrhage)[99] are simply different manifestations of this same tenet. In each of these instances, markedly abnormal physiology is accepted because randomized trials have shown worse outcomes when "normal" physiology and biochemistry are sought. Although methodologically sound trials involving surgical emergencies are difficult to perform and fraught with controversy,[100] they remain crucial to providing better and not just "normal" care.

Conclusion

Examples of recent innovations critical to the evolution of general surgical subspecialties include reduced blood loss and improved training in HPB surgery, TME resection and neoadjuvant therapies in colorectal surgery, the use of prosthetic mesh in outpatient hernia surgery, SLN theory and biopsy techniques in surgical oncology, endovascular skills in vascular and cardiovascular surgery and the acceptance of abnormal anatomy through damage-control procedures in trauma and critical care. The common denominator among all subspecialties, however, is the resultant improvement in patient care. This has most often been manifested as a decrease in morbidity and mortality. Whereas the introduction of surgical innovation into subspecialties rich in tradition is often cautious, surgeons must continue to pursue unique thinking, technological advances, improved training and systematic research.

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References

1. Innovation. *Merriam-Webster dictionary*. Available: www.merriam-webster.com/dictionary/innovation (accessed on 2009 Jan. 12).
2. Kuhn TS. *The structure of scientific revolutions*. 1st ed. Chicago (IL): University of Chicago Press; 1962.
3. Foster JH, Berman MM. Solid liver tumors. *Major Probl Clin Surg* 1977;22:1-342.
4. Kooby DA, Stockman J, Ben-Porat L, et al. Influence of transfusions on perioperative and long-term outcome in patients following hepatic resection for colorectal metastases. *Ann Surg* 2003;237:860-70.
5. Arnoletti JP, Brodsky J. Reduction of transfusion requirements during major hepatic resection for metastatic disease. *Surgery* 1999;125:166-71.
6. Mariette D, Smadja C, Naveau S, et al. Preoperative predictors of blood transfusion in liver resection for tumor. *Am J Surg* 1997;173:275-9.
7. Yamamoto J, Kosuge T, Takayama T, et al. Perioperative blood transfusion promotes recurrence of hepatocellular carcinoma after hepatectomy. *Surgery* 1994;115:303-9.
8. Jarnagin WR, Gonen M, Fong Y, et al. Improvement in perioperative outcome after hepatic resection: analysis of 1,803 consecutive cases over the past decade. *Ann Surg* 2002;236:397-406, discussion 406-7.
9. Farges O, Belghiti J, Kianmanesh R, et al. Portal vein embolization before right hepatectomy: prospective clinical trial. *Ann Surg* 2003; 237:208-17.
10. Mullen JT, Ribero D, Reddy SK, et al. Hepatic insufficiency and mortality in 1,059 noncirrhotic patients undergoing major hepatectomy. *J Am Coll Surg* 2007;204:854-62, discussion 862-4.
11. Dixon E, Schneeweiss S, Pasieka JL, et al. Mortality following liver resection in US medicare patients: Does the presence of a liver transplant program affect outcome? *J Surg Oncol* 2007;95:194-200.
12. Dimick JB, Wainess RM, Cowan JA, et al. National trends in the use and outcomes of hepatic resection. *J Am Coll Surg* 2004;199:31-8.
13. Dimick JB, Cowan JA Jr., Knol JA, et al. Hepatic resection in the United States: indications, outcomes, and hospital procedural volumes from a nationally representative database. *Arch Surg* 2003;138:185-91.
14. Birkmeyer JD, Siewers AE, Finlayson EV, et al. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002;346:1128-37.
15. Chen H, Merchant NB, Didolkar MS. Hepatic resection using intermittent vascular inflow occlusion and low central venous pressure anesthesia improves morbidity and mortality. *J Gastrointest Surg* 2000;4:162-7.
16. Jones RM, Moulton CE, Hardy KJ. Central venous pressure and its effect on blood loss during liver resection. *Br J Surg* 1998;85:1058-60.
17. Bismuth H, Castaing D, Garden OJ. Major hepatic resection under total vascular exclusion. *Ann Surg* 1989;210:13-9.
18. Dixon E, Vollmer CM Jr, Bathe OF, et al. Vascular occlusion to decrease blood loss during hepatic resection. *Am J Surg* 2005;190:75-86.
19. MacKenzie S, Dixon E, Bathe O, et al. Intermittent hepatic vein–total

vascular exclusion during liver resection: anatomic and clinical studies. *J Gastrointest Surg* 2005;9:658-66.
20. Heriot AG, Karanjia ND. A review of techniques for liver resection. *Ann R Coll Surg Engl* 2002;84:371-80.
21. Belghiti J, Marty J, Farges O. Techniques, hemodynamic monitoring, and indications for vascular clamping during liver resections. *J Hepatobiliary Pancreat Surg* 1998;5:69-76.
22. Man K, Fan ST, Ng IO, et al. Tolerance of the liver to intermittent pringle maneuver in hepatectomy for liver tumors. *Arch Surg* 1999; 134:533-9.
23. Belghiti J, Noun R, Zante E, et al. Portal triad clamping or hepatic vascular exclusion for major liver resection. A controlled study. *Ann Surg* 1996;224:155-61.
24. Petrowsky H, McCormack L, Trujillo M, et al. A prospective, randomized, controlled trial comparing intermittent portal triad clamping versus ischemic preconditioning with continuous clamping for major liver resection. *Ann Surg* 2006;244:921-8, discussion 928-30.
25. McKay A, Sutherland FR, Bathe OF, et al. Morbidity and mortality following multivisceral resections in complex hepatic and pancreatic surgery. *J Gastrointest Surg* 2008;12:86-90..
26. Heald RJ. The "Holy Plane" of rectal surgery. *J R Soc Med* 1988;81: 503-8.
27. Heald RJ, Husband EM, Ryall RD. The mesorectum in rectal cancer surgery — The clue to pelvic recurrence? *Br J Surg* 1982;69:613-6.
28. MacFarlane JK, Ryall RD, Heald RJ. Mesorectal excision for rectal cancer. *Lancet* 1993;341:457-60.
29. Wibe A, Moller B, Norstein J, et al. A national strategic change in treatment policy for rectal cancer — implementation of total mesorectal excision as routine treatment in Norway. A national audit. *Dis Colon Rectum* 2002;45:857-66.
30. Kapiteijn E, Kranenbarg EK, Steup WH, et al. Total mesorectal excision (TME) with or without preoperative radiotherapy in the treatment of primary rectal cancer. Prospective randomised trial with standard operative and histopathological techniques. Dutch Colo-Rectal Cancer Group. *Eur J Surg* 1999;165:410-20.
31. Arbman G, Nilsson E, Hallbook O, et al. Local recurrence following total mesorectal excision for rectal cancer. *Br J Surg* 1996;83:375-9.
32. Havenga K, Enker WE, Norstein J, et al. Improved survival and local control after total mesorectal excision or D3 lymphadenectomy in the treatment of primary rectal cancer: an international analysis of 1411 patients. *Eur J Surg Oncol* 1999;25:368-74.
33. Randomised trial of surgery alone versus surgery followed by radiotherapy for mobile cancer of the rectum. Medical Research Council Rectal Cancer Working Party. *Lancet* 1996;348:1610-4.
34. Randomized study on preoperative radiotherapy in rectal carcinoma. Stockholm Colorectal Cancer Study Group. *Ann Surg Oncol* 1996;3: 423-30.
35. Improved survival with preoperative radiotherapy in resectable rectal cancer. Swedish Rectal Cancer Trial. *N Engl J Med* 1997;336:980-7.
36. Peeters KC, Marijnen CA, Nagtegaal ID, et al. The TME trial after a median follow-up of 6 years: increased local control but no survival benefit in irradiated patients with resectable rectal carcinoma. *Ann Surg* 2007;246:693-701.
37. Sauer R, Becker H, Hohenberger W, et al. Preoperative versus postoperative chemoradiotherapy for rectal cancer. *N Engl J Med* 2004; 351:1731-40.
38. Sebag-Montefiore D. Routine short course pre-op radiotherapy or selective post-op chemoradiotherapy for resectable rectal cancer? Preliminary results of the MRC CR07 randomised trial. ASCO Annual Meeting Proceedings Part I. 2006 June 2–6; Atlanta, Ga. *J Clin Oncol* 2006;24(Suppl):3511.
39. Read RC. The centricity of Bassini's contribution to inguinal herniorraphy. Am J Surg 1987;153:324-6.
40. Rutkow IM, Robbins AW. Demographic, classificatory, and socioeconomic aspects of hernia repair in the United States. *Surg Clin North Am* 1993;73:413-26.
41. Lichtenstein IL, Shulman AG, Amid PK. The cause, prevention, and treatment of recurrent groin hernia. *Surg Clin North Am* 1993;73: 529-43.
42. Moiniche S, Hesselfeldt P, Bardram L, et al. Pain and convalescence after ambulatory inguinal herniotomy during local anaesthesia [Article in Danish]. *Ugeskr Laeger* 1995;157:424-8.
43. Aufenacker TJ, van Geldere D, van Mesdag T, et al. The role of antibiotic prophylaxis in prevention of wound infection after Lichtenstein open mesh repair of primary inguinal hernia. A multicenter double-blind randomized controlled trial. *Ann Surg* 2004;240:955-61.
44. Luijendijk RW, Hop WC, van den Tol MP, et al. A comparison of suture repair with mesh repair for incisional hernia. *N Engl J Med* 2000;343:392-8.
45. Hachisuka T. Femoral hernia repair. *Surg Clin North Am* 2003;83: 1189-205.
46. Mouton WG, Otten KT, Weiss D, et al. Preperitoneal mesh repair in Spigelian hernia. *Int Surg* 2006;91:262-4.
47. Muller-Stich BP, Holzinger F, Kapp T, et al. Laparoscopic hiatal hernia repair: long-term outcome with the focus on the influence of mesh reinforcement. *Surg Endosc* 2006;20:380-4.
48. Martinez Insua C. Costa Pereira JM. Cardoso de Oliveira M. Obturator hernia: the plug technique. *Hernia* 2001;5:161-3.
49. Hynes DM, Stroupe KT, Luo P, et al. Cost effectiveness of laparoscopic versus open mesh hernia operation: results of a Department of Veterans Affairs randomized clinical trial. *J Am Coll Surg* 2006;203: 447-57.
50. Sugarbaker PH, Chang D. Results of treatment of 385 patients with peritoneal sruface spread of appendiceal malignancy. *Ann Surg Oncol* 1999;6:727-31.
51. Verwaal VJ, van Ruth S, de Bree E, et al. Randomized trial of cytoreduction and hyperthermic intraperitoneal chemotherapy versus systemic chemotherapy and palliative surgery in patients with peritoneal carcinomatosis of colorectal cancer. *J Clin Oncol* 2003;21:3737-43.
52. Greene FL, Kercher KW, Nelson H, et al. Minimal access cancer management. *CA Cancer J Clin* 2007;57:130-46.
53. Arnoletti JP, Bland KI. Neoadjuvant and adjuvant therapy for rectal cancer. *Surg Oncol Clin N Am* 2006;15:147-57.
54. Eisenberg BL, Judson I. Surgery and imatinib in the management of GIST: emerging approaches to adjuvant and neoadjuvant therapy. *Ann Surg Oncol* 2004;11:465-75.
55. US Cancer Statistics Working Group. United States cancer statistics: 1999–2006 Cancer incidence and mortality data. Available: http://apps.nccd.cdc.gov/uscs/
56. Gould EA, Winship T, Pholbin PH, et al. Observations on a "sentinel node" in cancer of the parotid. *Cancer* 1960;13:77-8.
57. Stojadinovic A, Nissan A, Protic M, et al. Prospective randomized study comparing sentinel lymph node evaluation with standard pathologic evaluation for the staging of colon carcinoma: results from the United States Military Cancer Institute Clinical Trials Group Study GI-01. *Ann Surg* 2007;245:846-57.
58. Morton DL, Wen DR, Wong JH, et al. Technical details of intraoperative lymphatic mapping for early stage melanoma. *Arch Surg* 1992;127:392-9.
59. Krag DN, Weaver DL, Alex JC, et al. Surgical resection and radiolocalization of the sentinel lymph node in breast cancer using a gamma probe. *Surg Oncol* 1993;2:335-9.
60. Kim T, Giuliano AE, Lyman GH. Lymphatic mapping and sentinel lymph node biopsy in early-stage breast carcinoma. A metaanalysis. *Cancer* 2006;106:4-16.
61. Krag D, Weaver D, Ashikaga T, et al. The sentinel nodes in breast cancer: a multicenter validation study. *N Engl J Med* 1998;339:941-6.
62. Harlow SP, Krag DN, Julian TB, et al. Prerandomization surgical training for the National Surgical Adjuvant Breast and Bowel Project (NSABP) B-32 Trial. A randomized phase III clinical trial to compare sentinel node resection to conventional axillary dissection in clinically node-negative breast cancer. *Ann Surg* 2005;241:48-54.

63. Veronesi U, Paganelli G, Viale G, et al. Sentinel-lymph-node biopsy as a staging procedure in breast cancer: update of a randomised controlled study. *Lancet Oncol* 2006;7:983-90.
64. Morton DL, Cochran AJ, Thompson JF, et al. Sentinel node biopsy for early-stage melanoma accuracy and morbidity in MSLT-I, an International Multicenter Trial. *Ann Surg* 2005;242:302-13.
65. Morton DL, Thompson JF, Cochran AJ, et al. Sentinel-node biopsy or nodal observation in melanoma. *N Engl J Med* 2006;355:1307-17.
66. Purushotham AD, Upponi S, Klevesath MB, et al. Morbidity after sentinel lymph node biopsy in primary breast cancer: results from a randomized controlled trial. *J Clin Oncol* 2005;23:4312-21.
67. Nagatani S, Shimada Y, Kondo M, et al. A strategy for determining which thoracic esophageal cancer patients should undergo cervical lymph node dissection. *Ann Thorac Surg* 2005;80:1881-6.
68. Lucci A, McCall LM, Beitsch PD, et al. Surgical complications associated with sentinel lymph node dissection (SLND) plus axillary lymph node dissection compared with SLND alone in the American College of Surgeons Oncology Group Trial Z0011. *J Clin Oncol* 2007;25:3657-63.
69. McMasters KM, Noyes RD, Reintgen DS, et al. Lessons learned from the sunbelt melanoma trial. *J Surg Oncol* 2004;86:212-23.
70. *AJCC cancer staging manual*. New York (NY): Springer-Verlag; 2002.
71. Lucci A, Kelemen PR, Miller C III, et al. National practice patterns of sentinel lymph node dissection for breast carcinoma. *J Am Coll Surg* 2001;192:453-8.
72. Balch CM, Buzaid AC, Soong S-J, et al. New TNM melanoma staging sytem: linking biology and natural history to clinical outcomes. *Semin Surg Oncol* 2003;21:43-52.
73. Landry CS, McMasters KM, Scoggins CR. The evolution of the management of regional lymph nodes in melanoma. *J Surg Oncol* 2007;96:316-21.
74. Bembenek AE, Rosenberg R, Wagler E, et al. Sentinel lymph node biopsy in colon cancer. A prospective multicenter trial. *Ann Surg* 2007;245:858-63.
75. Selman TJ, Luesley DM, Acheson N, et al. A systematic review of the accuracy of diagnostic tests for inguinal lymph node status in vulvar cancer. *Gynecol Oncol* 2005;99:206-14.
76. Bembenek A, Gretschel S, Schlag PM. Sentinel lymph node biopsy for gastrointestinal cancers. *J Surg Oncol* 2007;96:342-52.
77. Gupta SG, Wang LC, Penas PF, et al. Sentinel lymph node biopsy for evaluation and treatment of patients with merkel cell carcinoma: the Dana-Farber experience and meta-analysis of the literature. *Arch Dermatol* 2006;142:685-90.
78. Paleri V, Rees G, Arullendran P, et al. Sentinel node biopsy in squamous cell cancer of the oral cavity and oral pharynx: a diagnostic meta-analysis. *Head Neck* 2005;27:739-47.
79. Zarins CK, Heikkinen MA, Lee ES, et al. Short- and long-term outcome following endovascular aneurysm repair. How does it compare to open surgery? *J Cardiovasc Surg (Torino)* 2004;45:321-33.
80. Dillon M, Cardwell C, Blair PH, et al. Endovascular treatment for ruptured abdominal aortic aneurysm. *Cochrane Database Syst Rev* 2007;CD005261.
81. Ford PF, Farber MA. Role of endovascular therapies in the management of diverse thoracic aortic pathology. *Perspect Vasc Surg Endovasc Ther* 2007;19:134-43.
82. Johnson CM, Hodgson KJ. Advanced endovascular training for vascular residents: What more do we need? *Semin Vasc Surg* 2006;19:194-9.
83. White RA, Hodgson KJ, Ahn SS, et al. Endovascular interventions training and credentialing for vascular surgeons. *J Vasc Surg* 1999;29:177-86.
84. Choi ET, Wyble CW, Rubin BG, et al. Evolution of vascular fellowship training in the new era of endovascular techniques. *J Vasc Surg* 2001;33:S106-10.
85. Cronenwett JL. Vascular surgery training: Is there enough case material? *Semin Vasc Surg* 2006;19:187-90.
86. Cronenwett JL, Liapis CD. Vascular surgery training and certification: an international perspective. *J Vasc Surg* 2007.
87. Creager MA, Goldstone J, Hirshfeld JW Jr, et al. ACC/ACP/SCAI/SVMB/SVS clinical competence statement on vascular medicine and catheter-based peripheral vascular interventions: a report of the American College of Cardiology/American Heart Association/American College of Physician Task Force on Clinical Competence (ACC/ACP/SCAI/SVMB/SVS Writing Committee to develop a clinical competence statement on peripheral vascular disease). *J Am Coll Cardiol* 2004;44:941-57.
88. Kouchoukos NT, Bavaria JE, Coselli JS, et al. Guidelines for credentialing of practitioners to perform endovascular stent-grafting of the thoracic aorta. *Ann Thorac Surg* 2006;81:1174-6.
89. Wheatley GH III, McNutt R, Diethrich EB. Introduction to thoracic endografting: imaging, guidewires, guiding catheters, and delivery sheaths. *Ann Thorac Surg* 2007;83:272-8.
90. Johnson JW, Gracias VH, Schwab CW, et al. Evolution in damage control for exsanguinating penetrating abdominal injury. *J Trauma* 2001;51:261-71.
91. Mattox KL. Introduction, background, and future projections of damage control surgery. *Surg Clin North Am* 1997;77:753-9.
92. Hirshberg A, Walden R. Damage control for abdominal trauma. *Surg Clin North Am* 1997;77:813-20.
93. Feliciano DV, Mattox KL, Jordan GL. Intra-abdominal packing for control of hepatic hemorrhage: a reappraisal. *J Trauma* 1981;21:285-90.
94. Smith CM. Origin and uses of primum non nocere — above all, do no harm! *J Clin Pharmacol* 2005;45:371-7.
95. Stone HH, Strom PR, Mullins RJ. Management of the major coagulopathy with onset during laparotomy. *Ann Surg* 1983;197:532-5.
96. ARDS Network. Ventilation with lower tidal volumes as compared with traditional volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* 2000;342:1301-8.
97. Kirkpatrick AW, Meade MO, Mustard RA, et al. Strategies of invasive ventilatory support in ARDS. *Shock* 1996;6:S17-22.
98. Hebert PC, Wells G, Blajchman MA, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. *N Engl J Med* 1999;340:409-17.
99. Clifton GL, Miller ER, Choi SC, et al. Lack of effect of induction of hypothermia after acute brain injury. *N Engl J Med* 2001;344:556-63.
100. Lemaire F. Emergency research: Only possible if consent is waived? *Curr Opin Crit Care* 2007;13:122-5.