Future developments

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The rapid development of minimally invasive surgery means that there will be fundamental changes in interventional treatment. Technological advances will allow new minimally invasive procedures to be developed. Application of robotics will allow some procedures to be done automatically, and coupling of slave robotic instruments with virtual reality images will allow surgeons to perform operations by remote control. Miniature motors and instruments designed by microengineering could be introduced into body cavities to perform operations that are currently impossible. New materials will allow changes in instrument construction, such as use of memory metals to make heat activated scissors or forceps. With the reduced trauma associated with minimally invasive surgery, fewer operations will require long hospital stays. Traditional surgical wards will become largely redundant, and hospitals will need to cope with increased throughput of patients. Operating theatres will have to be equipped with complex high technology equipment, and hospital staff will need to be trained to manage it. Conventional nursing care will be carried out more in the community. Many traditional specialties will be merged, and surgical training will need fundamental revision to ensure that surgeons are competent to carry out the new procedures.

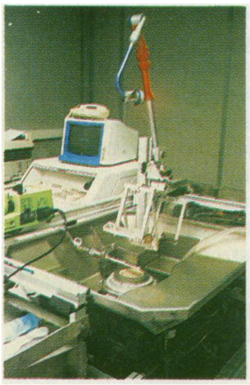

FIG 1—*Extracorporeal ultrasonic disintegrator*

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For the past 150 years mortality and morbidity for all surgical operations have been tacitly accepted as unavoidable parts of the therapeutic process, but since the early 1980s it has become evident that less invasive methods of interventional treatment in some areas have produced far fewer complications with a reduced risk of death and morbidity.[1] This realisation has given rise to the idea of minimally invasive treatment with its general aim "to minimise the trauma of any interventional process but still achieve a satisfactory therapeutic result."[2,3] More and more surgical and radiological procedures are being re-evaluated worldwide with a view to reducing operative trauma.

In the near future we will see many new procedures develop as a result of technological advances and fundamental changes in hospital design and surgical training.

Technological developments

VISION SYSTEMS

Adequate visual access is of paramount importance in minimally invasive operations. The present optical endoscopic systems are undergoing refinement and modification to digital systems with ever smaller electronic chip cameras. Binocular and autofocus zoom systems will give three dimensional perception and enhance imaging, and because the images are digitised they may then be manipulated and transmitted widely to several observers.[4] The operator will no longer view the interior of the body through a single eyepiece but will observe procedures on a high definition television monitor as a greatly magnified image. Magnification will not only improve safety in the operation but will enable other members of staff to see clearly and assist in the procedure. Accurate recording of procedures can also be archived for medicolegal and teaching purposes.

INSTRUMENTATION

Manipulatory instruments are still in their infancy but are rapidly becoming more sophisticated. Mechanical stapling and compressive anastomotic devices coupled with microwave or radio frequency heat energy will allow tissue welding and will undoubtedly replace simple suturing and pedicle ligation with needle and thread.[5,6] Direct tissue maceration by ultrasound[7] or high speed drills[8] will allow whole or partial removal of organs or tumours through tiny tracks while totally non-invasive physical mechanisms such as extracorporeal focused ultrasound[9] or microwave treatment[10] are already being used to break up and remove unwanted tissue (fig 1).

Endoscopically guided cutting and coagulation of tissues by diathermy is effective and safe, especially with recent refinements in bipolar diathermy technology. Thus replacement of this technology with laser systems (which are about three times more expensive) is probably superfluous despite the popularity of lasers with patients, who like their image of high tech magic. Lasers may, however, have more specific applications—such as calculus disruption, tumour ablation by photodynamic treatment,[11] and destruction of fibrous tissue[12]—that derive from their potential for differential absorption by different tissues and their capacity to focus high energies on to very small areas.

RADIOLOGY

Much of the work until recently undertaken by surgeons has become the responsibility of interventional radiologists or physicians and is concerned with clearing obstructed tubes. There is rapid development in biliary,[13] gastrointestinal,[14] and arterial stenting[15] with or without preliminary balloon dilatation under radiological control. For example, bile duct and oesophageal stenting are used for malignant occlusion and coronary artery disobliteration. Most manoeuvres are currently carried out by way of the natural lumen of an organ, but manipulation of solid organs by direct puncture under computed tomography or nuclear magnetic resonance imaging is progressing rapidly. A good example is the removal of the nucleus pulposus of prolapsed intravertebral discs by needle puncture, maceration, and aspiration.[16] Manipulations in the central vasculature by access through peripheral vessels is also progressing rapidly. Techniques such as directional coronary atherectomy are now under evaluation.[17]

ROBOTICS

The application of robotics to interventional therapy combined with x ray or ultrasound imaging is in its infancy. Several simple systems, however, have been successfully developed, including one for automatic transurethral resection of the prostate gland[18] and one for measuring and reaming the femoral medullary cavity before insertion of a hip prosthesis.[19] Robotic control of laparoscopic imaging by movements of the operator's head or eyes is under development.[20] The three dimensional accuracy and consistent reproducibility of automated procedures has still to be fully exploited but further instrumentation is likely to emerge. The digital projection of a computed tomographic image of an organ in a void has been achieved.[21] This virtual reality image (fig 2) can be "operated" on with ancillary instruments such as forceps or scissors that give tactile feedback to the operator. Slave robotic instruments track the movements of these instruments in order to operate on the patient's real organ and can be controlled from a nearby work station or even a distant hospital (fig 3). Thus, by electronic transmission it may be possible for surgeons in two different cities to operate on a patient in a third city by remote control.

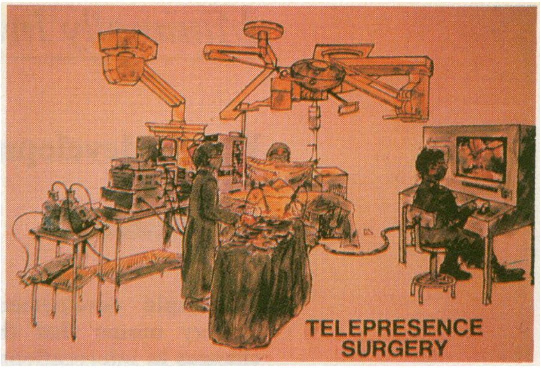

FIG 3—*Telepresence surgical work station remote from patient*

MICROENGINEERING

Microengineering, like microelectronics, is based on crystal technology.[22] It is now possible for tiny gears and mechanisms to be etched on a silicon crystal by photoreduction leaving a minute train of gears and levers to rotate around fixed pivot points. These micromechanisms can be combined with electronic controls to make microscopic electric motors less than 1 mm in size. Such motors would be capable of powering miniature instruments like scissors or forceps with a blade length of 1 μm or less and remotely controlled with a conventional pair of operating handles. These microscopic instruments could be introduced into body cavities or organs to perform operations that are currently impossible by macroscopic means. Similar motors could be used to power microscopic tractor mechanisms capable of carrying miniature imaging devices and of crawling through the gastrointestinal tract from above or below to take photographs or even biopsy samples of suspected lesions. We are presently operating on patients with instruments that are as crude as agricultural machinery compared with the technology of advanced avionics already in daily use.

Development of new materials will produce enormous changes in instrument construction. Memory metals, which change configuration at preset temperatures, will allow surgical instruments to assume different geometric shapes at various stages during an operation. This will reduce the need for mechanisms to achieve deformation and will allow production of heat activated scissors or forceps. Plastics that conduct electricity and metal coatings with the hardness of diamonds will soon be used in instrument making. The direct implantation of electronic motors into the body to power organs such as the bladder, erectile mechanisms, or artificial limbs is becoming established. While sensory implants for hearing loss now appear successful, combinations of sensory and motor powered electronic substitutions will probably lead to total replacement or organs such as the bladder or even the heart.

The possibilities of image manipulation and instrument development seem limitless, and open surgery by the hands in approach will appear quite gross when viewed with the standards that will be set in the next 20 years. By the year 2000 open surgery will appear as unusual as endoscopic surgery seems today. The technology needed for minimally invasive procedures will be expensive, but its application will be demanded by patients as they learn of the possibilities of cure by machine without bodily trauma. The enormous dependence of clinicians on instrument manufacturers for progress in minimally invasive treatment is apparent, and it is vital that they are integrated as equal partners in the interventional team.

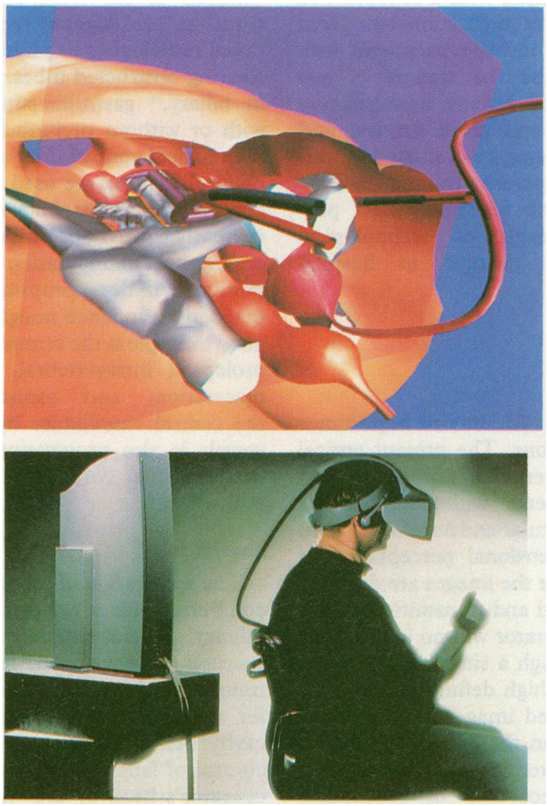

FIG 2—*Top: virtual reality image of lower abdomen showing great vessels, bladder, prostate, and rectum. Bottom: mask and glove required to produce virtual reality images*

Service implications and hospital design

The rapidity with which patients can recover from minimally invasive procedures results in an extremely rapid passage through a hospital.[23] Many patients do not require the hotel services currently provided by a major hospital complex and can be treated as day cases or with an overnight stay in a low dependency hostel unit.[24] Traditional hotel hospitals may become redundant and be replaced by "motels" with good transport facilities.

PATIENT HANDLING

The passage of a patient scheduled for treatment through the therapeutic complex should be fast and well organised. Patients undergoing minor procedures are commonly put to bed and then moved to a trolley and then to an operating table, and the whole sequence is reversed after the operation. Transport of patients must be revised based on the principles of production lines: patients should be mounted, conveyed, and treated on a pallet (fig 4) that is introduced at one end of the line and removed at the other without the need for multiple transfers. Hospital bureaucracy should likewise be simplified to match the rapid transit of patients.

OPERATING THEATRE

At present, operating theatres are inadequately provided with the instrumentation required for the performance of minimally invasive techniques. Units

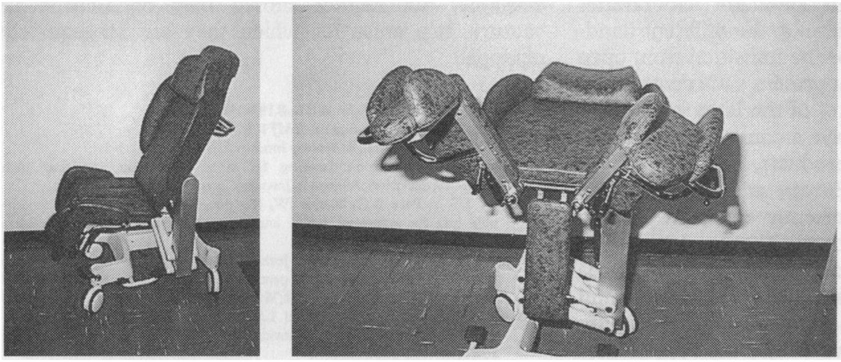

FIG 4—*Patient pallet for minimally invasive day care surgery in "park" and flat positions*

will require specially equipped treatment rooms (fig 5) with combined audiovisual, ultrasound scanning, and *x* ray facilities that are permanent installations and not, as they are now, occasionally wheeled in from dirty access corridors trailing wires. There must be specialist areas for the storage, cleaning, and rapid sterilisation of complex endoscopic and radiological instruments for immediate availability and reuse and a dedicated trained staff to manage them.

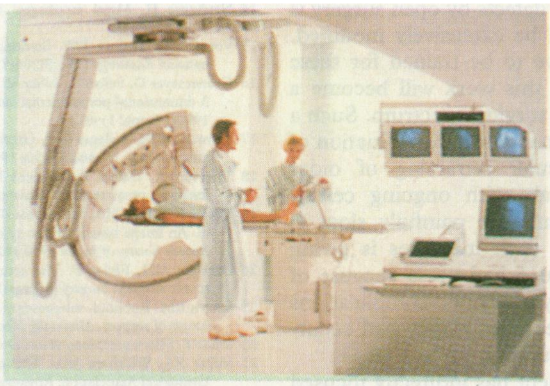

FIG 5—*Therapy room of the future*

NURSING

The requirement for classic inpatient nursing care will lessen, but the type of skills required in future will demand a greater understanding of high technology machinery. Conventional nursing care will become more community based with patients being visited in their homes before and after treatment. Communications and transport systems between interventional centres, homes, and community doctors and nurses will need to be greatly strengthened. Electronic monitoring of ambulatory patients is technically feasible, and with rapid link transmission to the treatment centre a large reduction in outpatient visits would be possible.

ANAESTHESIA

Anaesthesia and resuscitation will also undergo radical change in the next decade. As operations become less traumatic the requirement for profound anaesthesia and analgesia will decline, and techniques of sedoanalgesia[25] and local block will prove adequate for many interventions. The endoscopic placement of epidural catheters for the administration of specific blocking drugs to a particular nerve root or area is already being investigated, and the interruption of nerve impulses by electrical reverse potential has been shown to be effective in producing conduction block.[26]

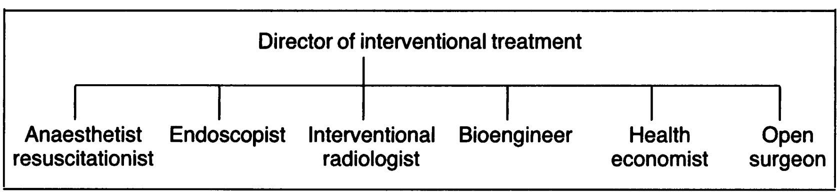

FIG 6—*Organisation of interventional treatment teams*

REALIGNMENT OF SPECIALTIES

It seems probable that traditional specialty alignments will be revised. All interventional treatment will be grouped into one division under the control of a physician director, who will, after preliminary diagnosis, assign each patient to the care of an appropriate member of the interventional team (fig 6). The anaesthetist will be responsible for preoperative and postoperative care. The endoscopist will deal with any organ (such as gall bladder, kidney, hernia, or appendix) endoscopically since the techniques are entirely analogous and thus cross traditional organ boundaries. Likewise, the interventional radiologist will treat all organ systems amenable to his or her techniques. The bioengineer will be consulted about suitable instrumentation, and the health economist will decide whether a recommended procedure is financially and politically acceptable. Finally, there will be the open general surgeon, whose role as conductor of the orchestra will be diminished to that of a member of a fully cooperative interventional team.

FINANCE

The financial corollary of these changes is that money should be transferred from simple hotel services in hospitals to technology that will probably be very expensive. Many of these changes may devolve on district general hospitals rapidly. Endoscopic cholecystectomy became the standard method for treatment of gall bladder disease within two years.[27] Endoscopic endometrial ablation[28] and endoscopically assisted hysterectomy,[29] appendicectomy,[30] hernia repair,[31] and pulmonary resection are being introduced quickly and will join with daycase arthroscopy[32] and transurethral prostatic resection[33] to reduce inpatient stay in hospital. Within a few years extracorporeal shockwave lithotripsy[34] and percutaneous endoscopic nephrolithotomy transformed open nephrolithotomy and ureterolithotomy into daycase and outpatient procedures, and such changes may soon come in other areas. Even if the profession is reluctant to acknowledge this shift in treatment then patient pressure will certainly be brought to bear on those clinicians who fail to adapt their practice.

Surgical training

The whole design of surgical training is in urgent need of overhaul. Present trainees are still being inducted down the path of conventional open surgical techniques that may become inappropriate in the next 10 years. In the United States it has been estimated that 95% of elective intra-abdominal surgery will be performed endoscopically within two years. The remaining areas for open surgical intervention will probably be in trauma and reconstruction, but most surgical or radiological interventions will not require open surgery even when complications develop. For example, haemorrhage from any artery can now be controlled by intravascular radiological embolisation or other manoeuvres, and similarly ductal obstruction may be stented or bypassed. Collections may be drained, and diseased organs repaired or removed endoscopically.

Evaluation of new operative competence is urgently needed because of the rapidity of changes in interventional treatment. Training programmes must be established so that interventionists' training is similar to that of airline pilots. A surgeon or radiologist should not be allowed to treat patients with sophisticated and potentially dangerous instruments without the experience of simulated operations and closely supervised procedural training. Fully equipped training centres should be established with simulator laboratories where interventionists can develop the different hand-eye coordination required for the transition from open to endoscopic techniques. At present such centres that do exist are under the control of the large instrument companies, who naturally have a considerable interest in promoting their own products, and have been established in continental Europe and in the United States. Only one centre currently exists in Britain, although two others are planned. The development of such facilities should be under the sponsorship of the Royal College of Surgeons or the universities and supported financially by the Department of Health, whose employees and patients will be the beneficiaries of these new skills. The need is urgent: the traditional method of "see one, watch a video, do one" is completely inadequate preparation for minimally invasive techniques.

It may be asked who will be left to open the abdomen when necessary. The need will decrease as the new techniques become further developed, but conventional surgery will still be needed to treat major traumatic injuries and disasters such as aortic aneurysmal rupture, although even the latter may now be dealt with by radiological wiring and stenting. The reconstruction of congenital defects by open surgery is probably inevitable but will be extensively modified. Specialist surgeons may have to be trained for these eventualities, but inevitably this work will become a minor segment in the whole surgical spectrum. Such a change suggests a need for mandatory re-evaluation of competence and in particular retraining of older clinicians at regular intervals with ongoing certification, but these mechanisms are painfully slow in gestation. Failure to adopt such measures is giving minimally invasive treatment a bad press because of media interest in a few highly publicised complications that would have passed unrecorded if they had occurred after conventional open surgery.

Minimally invasive treatment has indirectly focused much needed attention on the inadequacies of conventional surgical training. Surgical treatment has often been left in the hands of very junior doctors who have received only scanty practical instruction. A theoretical evaluation of competence by written or oral examination is totally insufficient to determine whether a clinician has gained the manual ability to carry out complex open or endoscopic surgery. A cabinet maker may have a theoretical idea of how to make an article but needs years of practical apprenticeship to achieve credible competence, and the same is true for surgeons.

Thus the concept of minimally invasive treatment has several consequences that need to be addressed by the medical and ancillary professions and the government. The benefits of such changes must be highlighted by well audited series reports, which in justification of any technique should report zero mortality and very few complications for any planned elective intervention. It must be recognised that a radical shift in the practice and philosophy of interventional treatment is becoming established, one which is enormously advantageous to the patient. The term "minimally invasive therapy" attempts to encapsulate the generalised concept of this avoidance of iatrogenic trauma. For those clinicians who may think that minimally invasive surgery evolved in 1989 with laparoscopic cholecystectomy it should be pointed out that this operation is but one small facet of a much wider range of lesser interventional procedures that have developed in the past 20 years and which have by no means been confined to general surgery. Doctors can no longer be allowed to traumatise patients with grossly invasive procedures when less damaging techniques that can achieve the same objective are now available, but neither should they be allowed to venture into areas for which they are inadequately equipped.

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Correction

American and European recommendations for screening mammography in younger women: a cultural divide?

A printer's error occurred in this article by Ismail Jatoi and Michael Baum (4 December, pp 1481-3). The legend to the picture should have read, "The benefits of mammography screening from age 40 remain unproved [not improved]."

ABC of Emergency Radiology—Maxillofacial radiographs

An editorial error occurred in this article by D W Hodgkinson and others (1 January, pp 46-51). The legends to figures 8 and 9 were transposed. Figure 8 shows the air-fluid level in the left maxillary sinus and figure 9 a fractured zygomatic bone complex.