The Royal Academy of Engineering

Engineering surgical innovation

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Biomedical engineering creates new medical technologies and systems that can greatly improve patient care and quality of life. The UK Focus for Biomedical Engineering is the Academy's forum for this increasingly important area of engineering in which the UK is taking a lead.

Introduction

In the past, it was usual for surgical interventions to be developed by surgical practitioners with an intimate knowledge of the procedure. It is only relatively recently that professional engineers have gone into the operating room and become closely involved in the development of surgical systems and devices. This has had a major impact on innovation.

Surgical interventions have undergone a considerable transition in the past 10 years, particularly in medical devices which have become smaller, more precise and cheaper. The use of robotic and computer-aided navigation systems, which can improve accuracy and simplify procedures that were previously either difficult or impossible to perform conventionally, has been particularly beneficial. However, it is in the areas peripheral to the actual intervention that most development has occurred. These include improvements in imaging, 3D modelling and the computer-assisted simulation and planning of procedures. These enable the surgeon to know beforehand exactly what is wrong, what is to be done, what effect this will have and, using post-operative imaging, to check that the surgery went as planned.

In soft-tissue surgery, the use of laparoscopic minimally invasive tools has developed into further applications. Improvements in the way that the operating tools are tracked by the laparoscopic camera are helping make procedures faster and safer.

Robotic technologies

Considerable publicity has been attached to the use of medical robots to provide precision and minimal invasiveness. An example is the Intuitive Surgical da Vinci telemanipulator, a robot originally designed for minimally invasive heart surgery. The surgeon sits at a master console and manipulates a slave unit comprising a telescope and two tool-carrying arms which are passed through 10 mm diameter incisions in the chest wall, thus avoiding the need to open the chest. The small number of procedures for which it was suited, together with a price-tag of $1.5 million and a cost of $1,500 disposables per procedure, made take-up less than expected. However, more recent applications in urologic surgery for treatment of prostate cancer have had widespread take-up which has made this tele-manipulator one of the most successful robot technologies. The benefits to patients of this minimally invasive surgery include little blood loss and fewer adverse outcomes, such as impotence or incontinence. Although the da Vinci provides no sense of touch, it has excellent 3D vision, allowing tissue to be excised precisely. Whilst some skilled laparoscopic surgeons claim similar results from manual procedures, certain hospitals are responding to patient demand and purchasing the robot.

Robotic orthopaedic surgery has a long pedigree, with the first clinical application by the Robodoc system for total hip replacement surgery in 1992. This autonomous system is positioned by the surgeon at the start location and the robot performs the procedure with no further surgeon involvement. Lack of surgeon involvement, together with many surgeons claiming they achieve similar results manually, has limited the take-up of this technology.

It is in orthopaedic procedures that are minimally invasive and difficult to perform well manually that robots can play a major role. Uni-condylar knee replacement is one such procedure where the development of a new type of "hands-on" robot shows considerable promise.

A "hands-on" robot consists of a type of telemanipulator in which the master control lever is placed near the tip of a slave arm. The surgeon holds the lever and can move the robot under power-assist whilst the robot can actively constrain the surgeon to a safe region, preventing damage to critical features such as ligaments.

This synergy of robot and surgeon ensures that the surgeon feels in charge of the procedure, unlike the more traditional "autonomous" orthopaedic robots, with the robot providing accuracy and safety. An example of a hands-on system is that of the UK company Acrobot, recently acquired by Stanmore Implants Worldwide, whose Sculptor robot is used to accurately implant a special type of uni-condylar knee prostheses.

Other technologies

One of the alternatives to robotic surgery is to use a navigation system. Here the position and orientation of LEDs (light emitting diodes) attached to tools and patients are tracked using a camera-based system. When the tools and patient are correctly aligned, a computer display lets surgery proceed. Navigation systems allow more accurate procedures than manual methods, but are not as precise as robots. The navigation system only guides and does not constrain the surgeon, so that if the surgeon moves off target, the warning from the system may come too late. In spite of these reservations, the intrinsically lower cost compared to robots makes navigation systems a preferred choice for some surgical procedures.

Innovations in sensing have had a particular impact on interventions. Sensors may be specialist, such as oxygen sensors, or the more common miniaturised position sensors or camera-based tracking systems. Imaging systems have been dominant, with miniature flexible endoscopes providing quality images of the operating site, but haptics, the study of the sense of touch, is now being heavily researched to replace the sensation that has been largely lost in minimally invasive laparoscopic procedures.

The use of ultrasound sensors to intra-operatively track tissue during a procedure is also significant, particularly in neurosurgery in which probes placed around the hole drilled surgically in the skull track tissue to compensate for brain-shift. The quality of ultrasound images is improving rapidly and is replacing the expensive MRI or intensified X-ray images currently used for intra-operative displays.

Non-surgical innovations

Non-surgical interventions are also being researched, such as high intensity focused ultrasound (HIFU). With this technique, drug-coated micro-bubbles are injected into the blood-stream and the drugs delivered by bursting them using HIFU.

In tissue engineering, small quantities of genetic material can be grown in the lab and injected into the body, potentially avoiding the need for surgery. However this scarce resource will need precise targeting and other special medical devices to deliver and support it.

Probably the most successful non-surgical robot treatment is that of Cyberknife, a frameless robotic radiosurgery system for accurately delivering radiotherapy. A linear particle accelerator is carried by a large robot and moved through a series of complex motions over the body to target tumours precisely.

Issues

In many instances, the pace of change has been slower than expected. Many of the problems inherent in the introduction of new technologies are non-technological. Resistance from surgical professionals will need to be overcome by means of long term data on patient outcomes, especially in areas of surgery where conventional methods are difficult. High technology procedures often take longer than conventional, with the benefits of improved results often seen only in the longer term. New technologies often require more training for surgeons and nurses and also can require more technical support in the operating room.

Conclusion

Engineering has had a major part to play in recent surgical innovations and will be an important component in future surgery.

Advanced systems are often more expensive than conventional technology and in the current economic climate healthcare providers may have a tendency to focus on the need for quicker, lower cost solutions rather than on the quality of interventions where improved outcomes may take time to become evident. However, in the past few years there has been a good synergy between medical professions and engineers working together. It is clear that the introduction of new technologies into surgery is happening at a greater pace and the contribution of professional engineers is a vital component of this change.

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