Orthopaedic Robotic Surgery

**Professor Brian L Davies, Emeritus Professor of Robotics, Imperial College London and Istituto Italiano di Technologia**

**Robodoc**

The earliest orthopaedic robot was Robodoc®, which was developed by IBM in 1986 for total hip arthroplasty. This gave rise to a commercial robot, which was the first orthopaedic surgical system used on humans in 1992. This was an autonomous device in which the patient was locked down and rigidly clamped. The surgeon placed the robot at the start position, pressed the on button and a predefined program carried out the task with no further activity by the surgeon, other than holding an emergency-off button.

The system was used in Germany until 2005 when a series of court actions blaming the robot for adverse outcomes were lodged. These proved to be largely unfounded, nevertheless it was sold to Curexo who continue to market the Robodoc system under the name Think Surgical Inc. The Robodoc system has failed to gain market share, maybe as it is autonomous and the surgeon is not in control?

**Acrobot**

My own experiences commenced in 1991 with a prostate resection robot, Probot, which was the first surgical robot to be used clinically. It became apparent that autonomous robots were not appreciated by surgeons. Therefore, in 1991, I started to develop a hands-on robot for unicompartmental knee arthroplasty (UKA). The surgeon held a high-speed rotary burr on the end of the robot which he or she moved freely within an allowed region. A preoperative 3-D CT scan was used to plan ‘no-go’ regions. The robot actively limits the surgeon, providing accuracy at the limits of the cut, a concept known as ‘Active Constraint Surgery’. In 1999 Professor Justin Cobb and I started a spin-off company Acrobot. We successfully undertook minimally invasive surgery in a number of British patients. Acrobot was sold to Stryker Ltd two months after the acquisition of Acrobot for $1.65 billion.

**Mazor**

Mazor was founded in 2001. In 2004 its first product Spine Assist was the first FDA approved spinal surgery robotic system. In 2008 the Renaissance Guidance System replaced Spine Assist, allowing minimally invasive surgery with reduced fluoroscopy times and excellent results for scoliosis and complex spinal deformity. It consists of a 12cm high parallel robot, which sits on a T-bar and drills pedicle screws with 1.5mm accuracy.

**Navio**

The Navio system was developed in Pittsburgh by Professor Jaramaz. It was used in Belgium for UKA in 2012. There is a handheld high-speed burr, which is controlled by a camera-based navigation system. The system is unusual in that it does not use a preoperative CT scan, but generates a plan based on touching the knee intra-operatively. Cutting no-go areas is prevented by a shield, which covers the cutting burr when the tracking system dictates. FDA approval was obtained in the USA 2012.
Current robotic surgery

Following the acquisition of the Mako system by Stryker, a number of large orthopaedic companies have acquired robotic surgery companies. This may be for prestige, to gain entry to this aspect of the prosthetic market or it may be because of a specific interest in the benefits of robotic surgery. These benefits include improved accuracy and repeatability, reduced strain on the surgeon, a structured workflow, simulation and the ability to undertake procedures that would otherwise not be possible. However, most orthopaedic robot companies have yet to make a profit and the major driver in the market is the selling of more prostheses.

In 2016, Smith & Nephew acquired the Navio robot and Zimmer Biomet purchased Medtech, whose robot is a variant of a small industrial robot. Medtech have CE Mark and FDA clearance for its Rosa Spine system and is traditionally more involved in neurosurgery. Mazor Robotics, also in 2016, signed an agreement with Medtronic, who have recently completed a $20 million investment to commercialise the Mazor X platform, an innovative guidance system for spinal surgery. The same X platform also supports an abdominal robot. Thus, Medtronic, are moving from a relatively simple system to a large, generic platform which can undertake a range of surgeries. Presumably, the basis is that a costly, but multi-purpose robot, is a better business proposition than a series of simpler specialised devices. This is presumably as complex software, with safety systems, planning and simulation sits more effectively alongside the surgery specific software. It should be noted that Google are involved with Johnson & Johnson in robot surgery research, which is an indicator that the Medtronic approach may appeal to other large organisations.

As these complex and expensive systems emerge, we are also seeing a move to small, low-cost, simple robotic medical devices. These are ‘smart tools’ which have specific advantages for specific tasks. For example Point Robotics is producing a smart drill that has a tiny parallel robot at the tip. The drill adapts in real time to accommodate patient movement and surgical hand tremor, thus drilling more accurately.

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Why have clinical applications been so few?

Given the rigid nature of bone, it would seem that orthopaedic surgery would be an obvious area for robotic applications. However, despite excellent research, clinical adoption remains low. One of the reasons is cost, even the simple Navio system retails at $400,000. Most of the costs are not in the device itself but in marketing, training, research and above all patent protection and litigation. Large companies have patented many variants, and defence of the patents is too expensive for small companies.

A further problem is showing clear clinical benefit from the robot. This is not simply a comparison with conventional open ‘jigs and fixtures’ surgery, but also with navigation systems, which do not need motorised control and are cheaper. Another competitor is the use of ‘patient-specific instruments’ (PSI) in which the fixtures are generated from CT scans. Many prosthesis suppliers favour PSI as it does not rely on costly navigation or robotic systems. However, whilst PSI seems to work well in experienced surgical hands, results with trainees have been less convincing.

It is important to compare robotic to conventional surgery. Like any other new system, robots have a learning curve, typically 25 to 30 cases. Thus the first 30 cases should be excluded, and if this is taken into account it is clear that Robots produce a more accurate and reproducible result than conventional navigation or PSI. This will in turn need to be correlated with better patient outcomes, which whilst the research is underway will take time.

The future

Orthopaedic robotics is at a new dawn and surgeons who hope all this ‘computer nonsense’ will disappear are in a minority. Regulatory needs are better understood and, whilst more onerous than in earlier days, are becoming more realistic. Thus although high cost robot systems will need to demonstrate cost-effectiveness it is likely that smart tools and devices will have an increasing part to play in delivering better healthcare at lower cost. Robotic surgery is less of a revolution and more a process of evolution and its bright future in orthopaedic surgery is assured.

Brian Davies is an Emeritus Professor of Medical Robotics at Imperial College London, where he has been since 1983, and is also a senior research investigator there. He has a PhD in Medical Robotics and a DSc. for Robotic and Computer Aided Surgery systems. He is a Fellow of the Royal Academy of Engineering since 2005. He developed the concept of Active Constraints in orthopaedic robots and in 1999 he was a co-founder of the spin-off company ACROBOT limited, who developed robots for MIS hip and knee joint replacement. He was their Technical Director until the company was acquired in 2010 by Stanmore Implants Worldwide, which in turn was bought by Mako Ltd and then by Stryker Ltd in 2013. In 2015 he was awarded the International Society of Technology in Arthroplasty (ISTA) life-time achievement award for research into the use of Robots in Surgery.

References

References can be found online at www.boa.ac.uk/publications/JTO or by scanning the QR Code.