

The evolution of robotic surgery

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The word ‘robot’ is thought to be derived from the Czech word ‘robota’ or meaning forced labour; the term was coined in Karel Čapek’s play R.U.R. (Rossum’s Universal Robots), which was written in 1920 and from this derivation the concept of robotics has evolved. The robot is a machine capable of carrying out a complex series of actions automatically, especially one that is programmable by a computer exemplified by half the robots in America that carry out predetermined tasks in the car making industry.

The term ‘robotics’ applied to surgery by the leading manufacturer and device currently used is, in fact, not a robot in the true sense of a programmable machine carrying out a pre-determined task, rather the da Vinci system is a master–slave system. Within the term robotics includes the concept of telesurgery, that is, the ability to operate remotely from the patient and site of surgery. The rationale of robotic surgery is to perform remote surgery or telesurgery and to enhance or increase the performance and outcomes of surgery over and above that achieved by the limitations of the human hand. The current explosion of the use of robotic surgical instruments we see today began in the beginning of the

millennium with American military funded research into systems that could be used for remote surgical operations, either a continent away at the front line or remote places including the space frontier.¹

In the early days of robotic surgery there were two competing systems: Intuitive Surgical’s da Vinci robot www.intuitivesurgical.com and Computer Motion Inc.’s ZEUS robot. These robots were based on a laparoscopic platform using trocar insertion and there were three key advantages over standard hand

together with the advantages described lent the system towards surgery that is carried out in a fixed bony cavity, where delicate suturing and reconstruction is required, therefore the initial evolution was towards cardiac surgery in the chest cavity and prostate surgery in the bony pelvis.^{2,3}

There was initial competition between the two early systems (although this was short lived) as with many emerging technologies Intuitive Surgical bought out Computer Motion System. All further

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laparoscopic surgery: enhancements of optics with a truly 3D computerised digital camera, wristed instruments as apposed to fixed laparoscopic instruments, allowing the natural hand movements of surgeons to be transposed in tight fixed spaces and finally, a more stable platform reducing the limitations of the table-side assistance in standard laparoscopic surgery. These earlier systems were limited compared to standard laparoscopic surgery by the heavy large cart gantry systems, which meant changing position from the original setup was time consuming, difficult and sometimes dangerous. This limitation

development was through Intuitive Surgical. Just as with the establishing and evolution of laparoscopic surgery, it took a single operation to establish the role of robotic surgery, which created the investment to develop further uses. In laparoscopic surgery it was cholecystectomy and for robotic surgery it proved to be radical prostatectomy for prostate cancer. After initial trials in Europe in cardiac and urological procedures, including robotic prostatectomy, the technique was established and evolved through the funding of the Vattikuti Institute in Detroit. This was under the guidance of

Mani Menon's team at the Henry Ford Hospital and it was from this centre that many of the high volume surgeons we see today, both in Europe and America, have gone on to establish their programmes.⁴

The first robot in the UK was bought as a research tool in general surgery at St Mary's Hospital in Paddington and in 2001 the first robotic prostatectomy was performed by a general surgeon, with guidance of an open robotic prostatectomy urologist pointing out the anatomy on the screen. The BBC covered the groundbreaking event at the time: news.bbc.co.uk/2/hi/health/1481105.stm. A year or so later a further machine was purchased at Guy's Hospital initially for the use in renal transplant surgery. After the initial operation at St Mary's no further prostate removals were performed owing to the difficulty and limited outcomes from the procedure against that achieved by open surgery at the time, enthusiasm for the procedure waned, whilst the Vattikuti Institute and others began to establish high volume centres. In 2004 I was appointed to St Mary's and was given the opportunity to re-establish a robotic prostate programme and after putting together a team of consultants we established the first recognised robotic prostatectomy programme in the UK.⁵ From a handful of prostatectomies performed this way it has now become the established gold standard for robotic prostatectomy.⁶

Although the robot was originally thought to be aimed mainly at cardiac surgeons⁷ the large camera and trocar instruments that had to be placed in-between the rib cage, limited its application, but at the same time cardiac surgery was undergoing a huge metamorphosis, after the establishment of coronary balloon angioplasty and stenting reducing the number of cardiac open operative procedures. For this reason, cardiac surgery has not adopted the technology and it remains a relatively small part of the specialty. However, once urologists became comfortable with the technology, they applied it to other operations including cystoprostatectomy. It has also proved to be particularly helpful in partial nephrectomy by reducing the warm ischaemia time with a slicker, faster hand suturing with the device.⁸⁻¹⁰

In the last five years or so with the

evolution of small instruments, better reach and a table motion system (which is about to be introduced by Intuitive), the robot can change position within the abdomen or endocavity without undocking, making feasible a plethora of new surgical applications with the prospect of most operations coming into the sphere of the robotic device.

After being initially a start up company, which licensed the established department of defence funding prototype system, the extraordinary clinical and commercial success of Intuitive Surgical with the da Vinci system has prompted other clinicians and basic engineering laboratories around the world to develop other platforms. The Amadeus platform from Titan Medical in Canada has also teamed up with a German aerospace agency, which will also incorporate imaging tools such as real-time

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ultrasound imaging. www.titanmedicalinc.com/titan-medical-inc-completes-amadeus-compos. There are also systems developing haptic or force feedback into robotic surgical systems one of which is developed in the Netherlands called 'Sofie' which is short for the Surgeons Operating Force Feedback Interface Eindhoven.¹¹

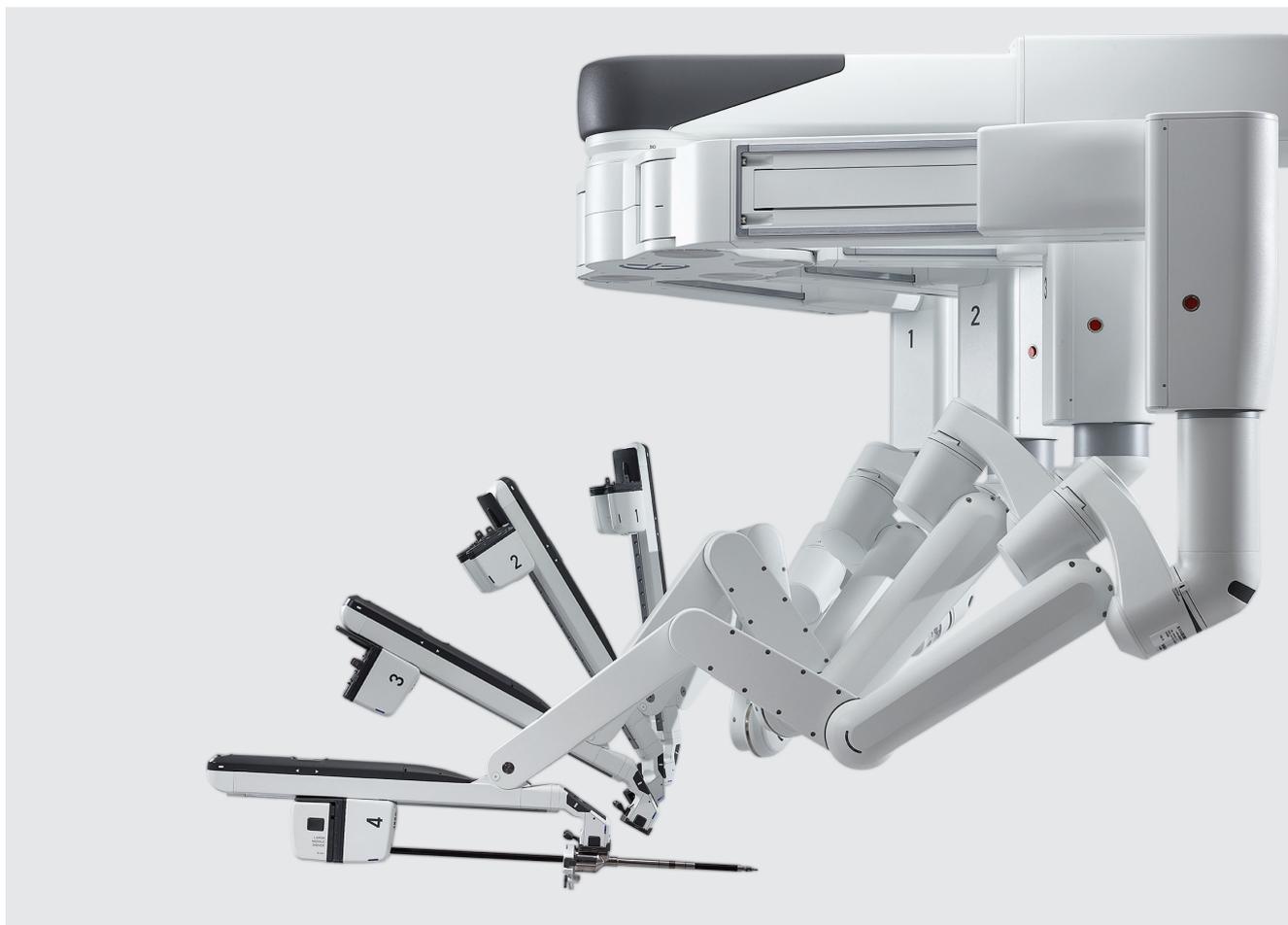
A further Department of Defence-funded robot in America is the Raven system,¹² similar to the concept of the da Vinci, this funded research was aimed at deploying robotic surgery capabilities in remote conflict areas to be controlled by unmanned aerial vehicles, which are currently used extensively by the military as weapons (citris-uc.org/telehealth/project/raven-surgical-robotic-system/). All these tools are evolving to enable traditional surgical approaches to be applied remotely and also to be carried out more reproducibly using robotic

instruments and arms. At the same time these technologies have been developed, other forms of surgical or radiological extrinsically delivered approaches to treating disease have equally evolved. Added to which during this decade imaging has vastly improved with the fusion of these evolved technologies, fresh approaches to the way we treat disease can be addressed and is already being explored now.

High intensity focused ultrasound (HIFU) is another technology I have been involved in longer than robotics and I have been lucky enough to apply its use in the treatment of prostate cancer. This is where high frequency sound waves are focused to a point to generate heat using computerised imaging technology based on ultrasound currently to map and treat an area of disease or an organ.

I presented one of the world's first comparison studies between whole gland HIFU and da Vinci robotic prostatectomy for treating prostate cancer.¹³ The findings were interesting in that the side effect profiles were relatively similar, with slight advantage towards HIFU. In whole gland HIFU treatment however, the oncological outcome was inferior to robotic surgery and yet interestingly a third of the HIFU-treated whole gland prostate cancer patients had a surgically equivocal result, in that they had undetectable PSAs following the procedure, demonstrating that complete surgical removal could be achieved in a third of the patients. (www.roboticprostatesurgery.co.uk)

Because surgical removal (open, robotic or laparoscopic) proved oncologically to be more superior in terms of outcome with no significant benefit in terms of complications, whole gland HIFU has largely fallen by the wayside, however, over the same period the evolution of MRI in the diagnosis of prostate cancer has undergone a rapid improvement. Prior to 2009 MRI was very poor at picking up prostate cancer but since then it has become increasingly sensitive and specific for picking up prostate cancer, with specificity as high as 95%. This has allowed the concept of focally treating prostate cancer to become a real possibility.¹⁴ Together under the guidance of the UCH programme in the UK and at The Royal Marsden where I work, we have completed multicentre trials. This trial is called The



Index Study,¹⁵ which looks at the clinical outcome of focally treated prostate cancer and is designed to assess its role in comparison to whole gland treatment. Initial data is encouraging, however, as with all assessment of oncological treatments, longer follow-up and further studies are required to establish whether focal therapy is superior to active surveillance in the treatment of prostate cancer and equivalent to whole gland treatments with a lesser morbidity, which is clearly the aim of all clinicians in treating prostate cancer.¹⁶

As real-time imaging of organs and cancer evolves, extracorporeal delivered energy tools using computerised pre-programmed robotic systems will continue to evolve more accurate and specifically targeted treatment for a plethora of diseases. One such advance is the robotic radiotherapy arm of the CyberKnife external beam radiotherapy device www.cyberknife.com/. This couples real-time imaging to customise the programmed radiotherapy treatment to the movement

of the prostate during treatment. The computerised robotic technology allows a higher dosage of radiotherapy over a shorter period to be dispensed without a necessity for hormone treatment; this is coupled with the radiotherapy shortening the delivery from nearly two months to 10 days and because it is thought to be more conformational, it will hopefully improve clinical outcomes and reduce morbidity.

I am currently part of the first randomised control trial comparing robotic surgical prostatectomy with the da Vinci robot and the CyberKnife radiotherapy robotic system, this is being lead by The Royal Marsden. With over 35 patients recruited to date it will be interesting to see how these robotic technologies compare.

It is exciting to see the evolution of these new technologies after being a founding faculty member of The European Urological Robotic Surgery meeting at the turn of the millennium. This initially small group of pioneering enthusiasts has evolved into a large annual

conference reflecting the exponential growth of robotic surgery in urology.¹⁷ This year for the first time however, a paper was presented using the pre-programmed use of high-intensity focused ultrasound and real-time imaging to focally treat prostate cancer. As the robotic instrumentation becomes smaller with the potential of single port technology evolving and real-time imaging, delicate stereotactic surgical applications that so far have eluded robotic surgery will become feasible. This will include craniofacial surgery and indeed neurosurgery, surpassing the need for the highly skilled and steady neurosurgical human hand.

Robotic surgery is also revolutionising the training of surgeons and therefore mitigating the impact of the early learning curve of training surgeons on patients. With the twin-cart training platform from da Vinci and presumably other providers in due course, we are able to train surgeons on table and supervise real-time by switching between the platforms. Prior to this step, computerised training modules have been

devised similar to video game technology, which enables key steps and skills to be acquired to a high level before exposing the surgeon to a patient on the table. This can only be a significant step forward to minimise the impact of any learning curve on patient outcomes and also to readily train up competent surgeons without the necessity of exposure to large numbers of patients to attain such skills. There are also specific systems designed for training such as the dV trainer (www.mimicsimulation.com/products) and Ross training

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platforms (www.simulatedsurgicals.com/ross2.html).

Robotic surgery is focused currently on console manipulated laparoscopic instruments and extracorporeal power sourced image-guided tissue destruction. There are a number of revolutionary concepts being trialled, such as swarm robots using small simple robotic devices, which can be orchestrated to perform complex functions similar to the conductor of a classical orchestra. The idea being that tiny, simple, cheaply made multiple devices could be inserted into the abdominal cavity to be directed to perform specific tasks similar to the swarm or the squadron effect of ant or termite colonies.

There is the concept of surgical genetic engineering by removing defective genes and replacing them with normal genes by the development of NanoKnife® surgical tools and femtosecond lasers. However, such conceptual technology whilst having been demonstrated in basic science research, will take 20 to 30 years before we see an evolution of this technology to direct patient care. A more likely technology on the near horizon is likely to be endoluminal robotically controlled devices.

Although robotic surgery has revolutionised urological surgery, in particular robotic prostatectomy and

partial nephrectomy, the majority of operations are still not performed robotically. Gynaecology has seen the next greatest take up, but with the imminent impact of new robotic systems, smaller instrumentation and the advent of real-time intraoperative imaging, the majority of surgical specialties will be adopting robotic surgery as the norm.

The value and need for telesurgery or remote operating surgical systems remains to be established,¹⁸ but the enhanced powers of robotically engineered and delivered systems have convinced the majority of urological surgeons to move to the robotic platforms. In particular testament to this is that many of the pioneering minimally invasive surgeons of Europe who have developed enormous expertise using standard laparoscopic techniques, have now moved across and adopted the robotic platform. In the end, whilst the outcomes may have been equivalent with their standard laparoscopic technique, it is easier and more ergonomic for the surgeon to use robotics. At the end of the day if it is easier for the surgeon it is invariably easier for the patient. ♦

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