

CAN CARBON NANOTUBES OF AEROGEL DEVELOP & IMPROVE ROBOTIC
SURGERY?



BY

DEREK TSIANG

EDWARD CUNNINGHAM-OAKES

ZIKA MUWOWO

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ABSTRACT

The initial concept of our paper developed from a member of our team of researchers' interest in the concept and mechanics of how machines could be used in surgery and the other researchers' profound interest in nanotechnology. Our combined interests lead to our discovering of an article by Dr. Lei Zhei on Carbon Nanotube Aerogels, and their potential uses. We then researched this further and we were enthralled by what we found as one new development lead to another; from the seemingly transcendent (when compared to most other materials) properties of Aerogels (and more importantly MWCNT Aerogel), to the pinnacle of technological brilliance in the form of the highly advanced Da Vinci Surgery system. It was not long before we decided that this could be one most promising and fascinating areas of nanotechnology to date, and were eager to share our findings with others in this research paper in the hopes they would develop an appreciation for this field (and for nanotechnology) as we undoubtedly have.

INTRODUCTION

Robotic surgery has been at the forefront of surgical medicine only very recently. Involved, are the use of robotic devices in the performance of surgical procedures. The use of robotic surgery has increased, especially for urological procedures, as they look to be as minimally invasive as possible. The mechanical devices have been manufactured to have the capability to handle instruments and tools surgeons need with dexterity and at the same time be accurate and precise. It also enables surgeons to operate with a completely steady hand and throughout all of this the surgeon is in full control and able to perform as effectively if not more than when physically doing the surgery. Some experts see the use of robots as the future of surgery, although there is still considerable debate about the usefulness and cost-effectiveness of robotic surgery techniques. The very latest in robotic surgery include systems such as Da Vinci surgery^[1], SurgRx, Inc. (USA), GfE Medizintechnik (Germany), Smith & Nephew, Inc. (USA) and AcryMed, Inc. (USA)^[2] where the latest, more technologically advanced and most efficient equipment is used for robotic surgery. Three types of robotic surgery take prominence, shared-control, remote and supervisory procedures. In shared-control procedures, the robots are used to hold things in position such as limbs or equipment including cameras and the like and even to reach places that are hard to reach in the body. It has the simple aim to ease the work of the surgeon in removing the risks presented by hand tremor of the surgeon. The second, remote procedures enable surgeons to perform surgery, whilst at a different location to the patient. Enabling experts in certain surgical fields to perform them even when unable to be where the patient is. Finally, pre programmed robotic surgery. This would be the least common of

the three as it is the newest. The surgery is programmed into the surgical robot and it is then left to carry out the procedure unmanned but supervised by the surgeon.^[3]

Problems associated with robotic surgery

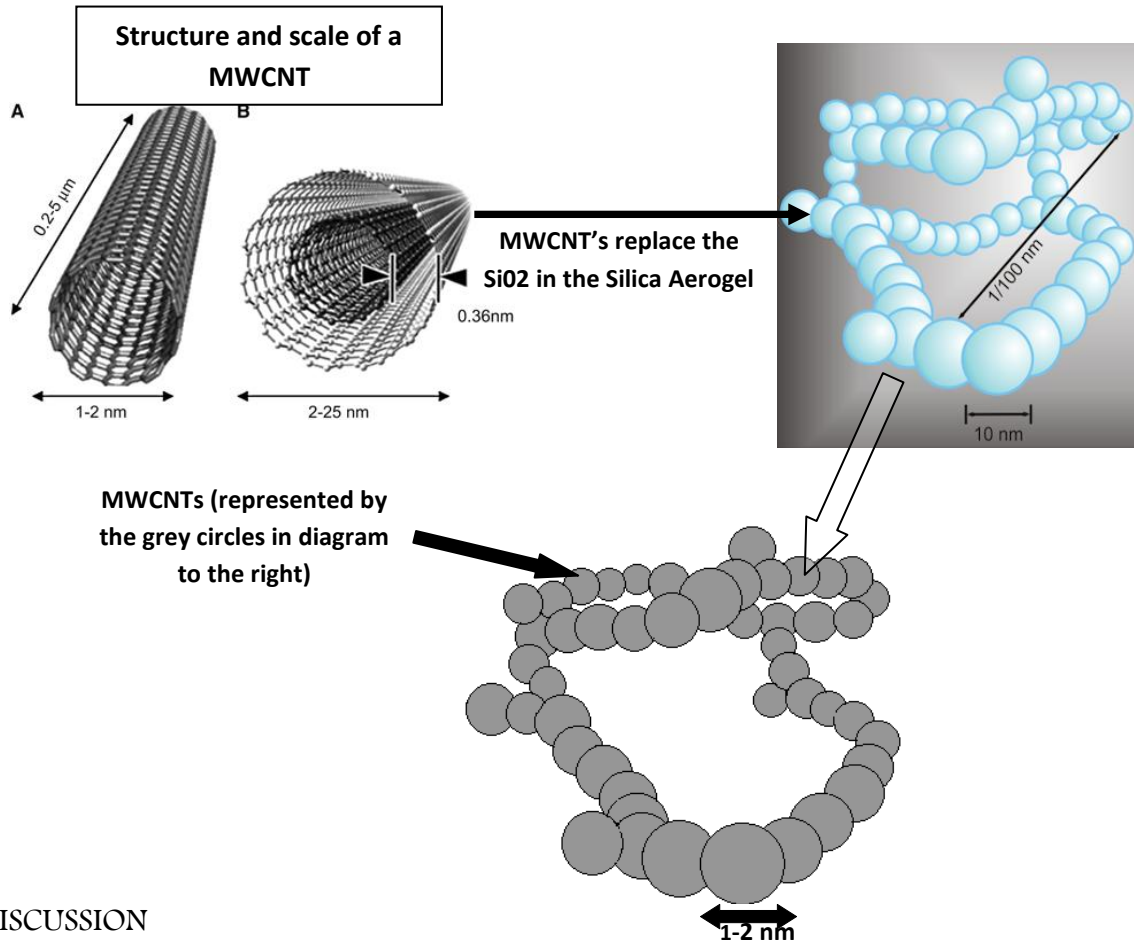
The emergence of robotic surgery has not been without challenges and difficulties. In this paper three such problems will be identified and discussed and solutions provided. The first area of challenge has to do with the robot being deficient in force feedback to the surgeon controlling it; thereby limiting the “recreation” of what the surgeon is doing. Consequently this could hinder the surgeon performance. Secondly, the issue of eliminating even the slightest of hand tremor of the surgeon. Hand tremor transferred on makes robotic surgery ineffective and does not advance surgery.^[4]

The third problem is that robots can only go by what they have been programmed to do. They do not have the same judgment as humans. In theory robots may be faster at performing surgery, however this may not be so in every instance. When it comes to surgeons’ maintenance of the skills needed to perform robotic surgery, it is not easy as these operations are not the most common. Hence, when surgical procedures are formed with robots, collision of instruments along with technical malfunction occur,^[5] not only slowing the operation but also putting the patient at risk. Nanotechnology today has risen to the advanced level that allows these problems to be solved.

Nanotechnology has the potential to advance robotic surgery (RS) by utilising Aerogel that contains Multi-Walled Carbon Nanotubes (MWCNTs). An Aerogel is one of the lightest solid materials known to man. Aerogels are created by super critically drying the liquid component of a gel, conserving the molecular structure of the original gel and then filling it with a gas. Aerogels which is approximately only three times heavier than air have excellent thermal insulation (with a melting point of approximately 1473 K) and on a micro structural level is dendrite (meaning it has a crystal-tree like structure) which leads to it being able to bear loads which are far greater than its own weight. The most common form of aerogel is Silica Aerogel, the world’s lowest density solid. Silica Aerogel consists of nanoparticles of Silicon Dioxide which are arranged in a porous network. However, by replacing the Silica found Aerogel with MWCNTs and combining it with robotic surgery (see fig. 1), we can improve the sensitivity of the robotic arms and hands used in RS so they are more sensitive, an ability which is crucial and allow them to distinguish between different surgical apparatus.

The possibility of increasing the sensitivity of RS is possible to RWCN aerogel having such a low density that it can be used to detect and trace any small changes in pressure.

Figure 1



DISCUSSION

We can't be certain exactly how many scientists have worked with aerogel since the beginning of the new century. What we can be certain of however, is the scientist who is arguably the founder of all aerogel related research, Samuel Stephens Kistler ^[6]; who prepared the first aerogels and spent a large part of the past century studying their properties and uses.

Kistler accomplished creating the first aerogel by supercritically drying the fluid component of a gel, and replacing it with a gas. Supercritical fluid drying has advanced greatly since Kistler's era, and is now a much simpler feat. Current development of aerogel involves the production of silica aerogel, carbon aerogel and alumina aerogels. Future development of aerogels include cadmium selenide quantum dots in a porous 3-D network, however this is for use in the semiconductor industry. ^[7]

Carbon aerogels are composed of particles with sizes in the nanometre range which are covalently bonded together. At the nanoscale, carbon aerogels are composed of nanoparticles of carbon with diameters approximately 1–2 nm. The first report describing a combination of aerogels and carbon nanotubes appeared in the *Journal of Non-Crystalline Solids* in 1994, produced by Dr. Arlon Hunt and Dr. Mike Ayers and their associate Dr. Wanqing Cao at Lawrence Berkeley National Laboratory. ^[8]

The carbon nanotubes are strong and also have impressive conductivity properties, which present the possibility of improving technology involving carbon aerogels we already use, and using this new MWCNT aerogel in technology such as sensors, actuators, electrodes and thermoelectric devices (as well as a replacement for many areas of the scientific field where silica aerogels are used). This will help in the event of robotic surgery. ^[9]

Robotic surgery is used so surgeons can perform endoscopic, non-invasive surgery, and thus reduce the risk of complications in surgery. Surgeons perform this by creating small cylindrical incisions in the patient (as opposed to the large incisions that are made in traditional surgery).

This piece of high-tech equipment is changing the face of surgery as we know it. With the help of carbon nanotubes of aerogel, surgeons can use their console to transmit high-speed electrical signals that communicate with the robotic arm platform. Since carbon aerogel is very conductive in electricity, it is perfectly suited for this job.

Since the CNTs of aerogels are excellent conductors of electricity, they can sense minuscule quantities (with the ability to sense a substance or object that weighs as little as 0.003527 ounces); this would make them ideal for sensory applications. ^[10]

The high definition of the 3D vision used during robotic surgery is achieved through carbon nanotubes (CNT), and with the recently developed integration of aerogels – which are good conductors of electricity – sensors are used to help produce and transmit the data to allow the surgeon to see a great amount of detail throughout the surgical field and onto the audio/visual data monitors during surgical procedures. The amount of detail visualization provided allows the surgeon to detect different tissue planes and critical anatomy. This results in increased surgeon confidence and an environment that leads to a greater surgical precision. Robotic surgery benefits not only the surgeon but also the patient. See the extracts below. ^[11]

The patient may experience the following benefits:

- Reduced trauma to the body
- Less anesthesia
- Often less blood loss and need for transfusions
- Less post-operative pain and discomfort
- Less risk of infection
- Shorter hospital stay
- Faster recovery and return to normal daily activities
- Less scarring and improved cosmesis

Benefits to the Surgeon:

- Enhanced 3-D Visualization
- Improved Dexterity
- Greater Surgical Precision
- Improved Access
- Increased Range of Movement
- Reproducibility
- Simplifies many existing MIS surgical techniques
- Makes difficult MIS operations routine
- Makes new MIS procedures possible in most surgical specialties

Robotic surgery is evidently still being researched into and developed by companies across the world because it is not at all cost effective. However, robotic surgery has a very promising future if the current technology will allow going beyond some of the current issues and is able to implement all the conceptual advantages of robotics. This is not ‘Star Trek’ science. Developments such as remote surgery can make this technology widely available; this is likely to boost this type of practice with potential benefits for standardization of surgical care and surgical education. ^[12]

Future developments on robotic surgery expand across medicine within a hospital. Since RS is known for a patient’s decreased length of hospitalization, a cost-benefit scheme is researched. As the success of RS becomes better known, militaries have expressed an interest of this technology for use in battlefield applications. Contracts have been made to develop a telerobotic surgical system for use in the battlefield that would allow medical personnel to treat wounded patients from a remote location. So in the future, a more

widespread use of robotic systems throughout the commercial and military sectors can be expected.

We foresee that medical robotics will have a significant influence over the next decade. Robots may be able to assist the surgeon with tools within the operation theatre. The robotic system could warn surgeons of incorrect trajectories or restrict the movements of the surgery away from dangerous or critical areas preventing vessels penetration or critical tissue damage.

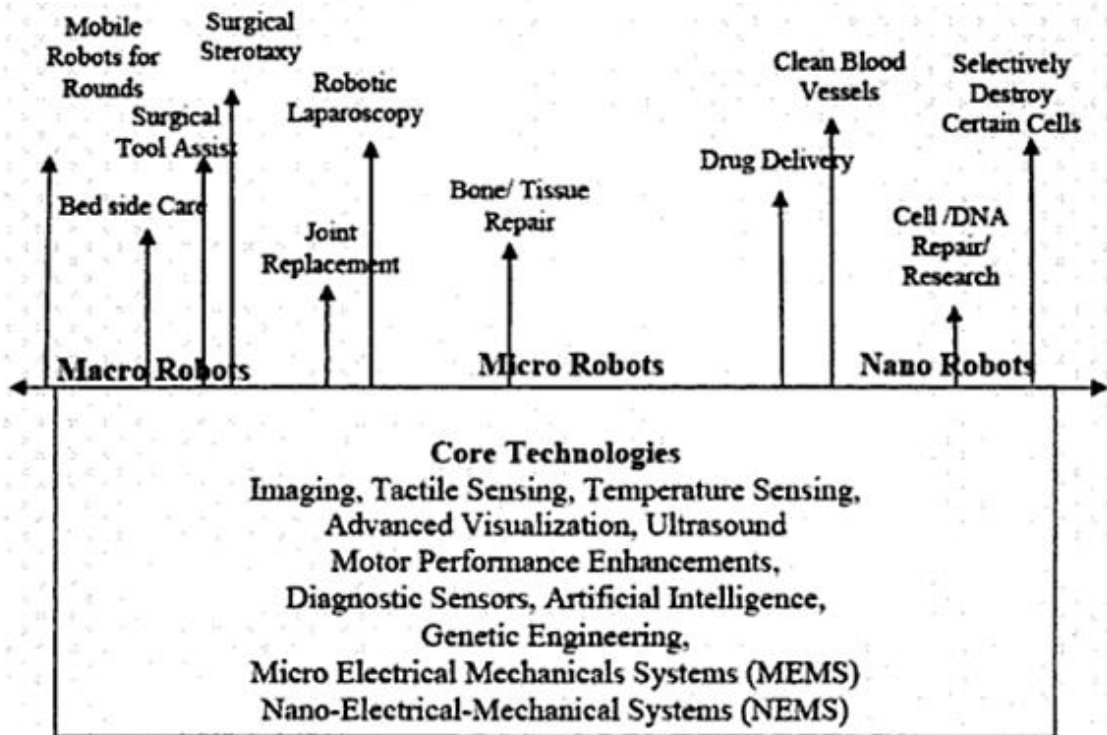
Robotic devices have been used in Cardiac surgery, Urology, Foetal Surgery, Paediatrics, Neurosurgery, Orthopaedics and many other medical disciplines. As with imaging technology, robotics may bring patient care and treatment a leap forward.

A good example of the use of robotics is for smaller patients (children) where precision is very important, (but difficult due to the small size of the patient). The Children's Hospital of Michigan and Detroit, MI. performs surgery using a robotic system in children. Their experience with their first 60 cases has been positive. ^[13]

With respect to the future of robotic technology in nano (and micro and macro) robotics, further development and improvement can be expected in the areas of robotic vision, diagnostic sensors and sensor fusion. ^[14]

Figure 2 below illustrates an overview of possible developments. As you can see, macro robots are mentioned – these should be able to interact with patients at their bedside and hand tools to surgeons at the operating table to robots built to interact with cells. There can be hybrid robots which have components built at many levels.

Figure 2



Core technologies and applications for nano, micro and macro robots

Figure 3; Table 1

TABLE 1. Advantages and Disadvantages of Conventional Laparoscopic Surgery Versus Robot-Assisted Surgery

	Conventional Laparoscopic surgery	Robot-assisted surgery
Advantages	Well-developed technology Affordable and ubiquitous Proven efficacy	3-D visualization Improved dexterity Seven degrees of freedom Elimination of fulcrum effect Elimination of physiologic tremors Ability to scale motions Micro-anastomoses possible Tele-surgery Ergonomic position
Disadvantages	Loss of touch sensation Loss of 3-D visualization Compromised dexterity Limited degrees of motion The fulcrum effect Amplification of physiologic tremors	Absence of touch sensation Very expensive High start-up cost May require extra staff to operate New technology Unproven benefit

As can be derived from figure 3 table 1^[15], robot assisted surgery has significant disadvantages, but in addition, advantages that out-weigh them. This includes improved dexterity and elimination of physiologic tremors. One disadvantage in figure 3 stood out to us – the absence of touch sensation. And with the help of aerogels, this is a problem with a potential solution.

In addition to this, the advantages of the surgeon him/herself compared to the robot are also significant.

TABLE 2. Advantages and Disadvantages of Robot-Assisted Surgery Versus Conventional Surgery

Human strengths	Human limitations	Robot strengths	Robot limitations
<ul style="list-style-type: none"> ● Strong hand-eye coordination ● Dexterous 	<ul style="list-style-type: none"> ● Limited dexterity outside natural scale ● Prone to tremor and fatigue 	<ul style="list-style-type: none"> ● Good geometric accuracy ● Stable and untiring 	<ul style="list-style-type: none"> ● No judgement ● Unable to use qualitative information
<ul style="list-style-type: none"> ● Flexible and adaptable 	<ul style="list-style-type: none"> ● Limited geometric accuracy 	<ul style="list-style-type: none"> ● Scale motion 	<ul style="list-style-type: none"> ● Absence of haptic sensation ● Expensive
<ul style="list-style-type: none"> ● Can integrate extensive and diverse information ● Rudimentary haptic abilities ● Able to use qualitative information ● Good judgment ● Easy to instruct and debrief 	<ul style="list-style-type: none"> ● Limited ability to use quantitative information ● Limited sterility ● Susceptible to radiation and infection 	<ul style="list-style-type: none"> ● Can use diverse sensors in control ● May be sterilized ● Resistant to radiation and infection 	<ul style="list-style-type: none"> ● Technology in flux ● More studies needed

Figure 3; Table 2

Whereas the strengths of the surgeon are prominent, his/her limitations cause conventional surgery to pale into insignificance when it comes to certain aspects. For example, the dexterity that a surgeon may have for a while – that is then lost to fatigue – can be kept by a surgical robot. Furthermore surgeons will have a limited ability to use quantitative information (as stated in figure 3 table 2^[16]) whereas surgical robots are computers; which we know are capable of holding more information than can be imagined.

All in all, an improvement to robotic surgery will not go unnoticed, making robotic surgery more reliable and more acceptable.

MWCNT Aerogels for Pressure Sensing

When MWCNT are made, they are able to return to their original shape once suppressed^[17], [as seen in this [video](#)] and have very conductive properties. It was Dr. Lei Zhai and his team who investigated the fact that these both lead to aerogels having the pressure responsive property (i.e. the resistance changes with the applied pressure)^[18]

Figure 4 shows the correlation.

The resistance of the aerogels decreases with the pressure (from 0 to 180 Pa) closer look, the pressure indicates that even a low as 5 Pa can cause a change in the resistance, demonstrating the potential of the MWCNT aerogels as ultrasensitive pressure sensor. A pressure sensor, which if combined with surgical robotics, will make a vast improvement.

The aerogel's resistance to the applied pressure becomes smaller when the pressure is higher than 180 Pa. Leading researchers

strong change in resistance behaviour could due to the pressure-induced increase of the MWCNT network density of the aerogels. A small pressure (0–180 Pa) increases the MWCNT network density around the percolation (filtering of fluids through porous material) threshold, and greatly decreases the resistance of the aerogels. In contrast, applying a larger pressure (>180 Pa) onto the MWCNT aerogels generates a MWCNT network density well above the percolation threshold, leading to a flat pressure vs. resistance curve as shown in Figure 4.

The change in resistance of the MWCNT aerogels as a result of repeated loading and unloading of 25 Pa (figure 4 part b) shows a rapid and instant resistance decrease (<0.2 S) with the loading of pressure, while, following the unloading of pressure, a complete and fast (<0.4 S) recovery is the observed result. These incredible pressure responsive properties of the MWCNT aerogel make it a promising candidate for pressure sensing and a more than sufficient aid to medicine through robotic surgery. ^[19]

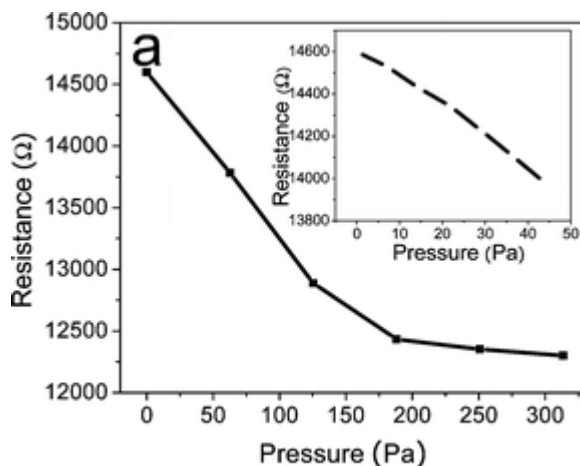


Figure 4 (a)
The resistance change of MWCNT aerogel with applied pressure. At low pressure, the resistance varies with the pressure.

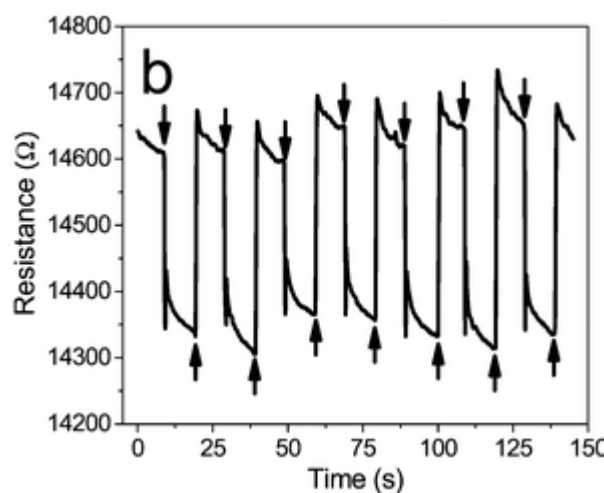


Figure 4 (b)
Change of MWCNT aerogel resistance with loadings. Arrows indicate the moments of the application and release of loading.

believe this

Ethics

As much as nanotechnology and robotic surgery have and will advance medicine, there are still key issues that need addresses. We must examine the ethics of developing nanotechnology and robotic surgery to minimise the adverse impacts in the future. These ethics include the idea of depth of knowledge and power that nanotechnology gives those who use it. Within medicine, this is more of a benefit than a danger; however, there are still risks of misuse of this power. Advanced nanotechnology placed in the wrong hands could be catastrophic not only in the medical realm but also universally. Dangers include the manufacturing of weapons at a smaller, ‘nano’ size, rampant nano machines, such as the gray goo scenario and other self-replicating nanomachines. This would lead to a whole other crisis but still stem from the research and development of nanotechnology generally and even medicine specific. Furthermore, society could be face with products of nanotechnology that are on some level of immorality. Medically related, medical devices could be built into needles narrower than a bacterium, allowing a whole array of possibilities, many of which not positive. In relation to robotic surgery, we know that it currently is and will carry on opening new doors in the near future of surgical practice. However, robotics is essentially computer based and we have the knowledge that computers fail or crash preventing them from working at their full and undoubtedly significant capacity. This raises the question of whether this could happen to robotics in medicine and if so could the consequences be dangerous? Many want to know if we can be sure that errors in robotic surgery will not happen now or later with future developments. ^[20]

The future of robotic surgery

The combination of current surgical robots and aerogels is a sneak peek into the near future of nanotechnology in medicine. Technically, there is still a lot to be done before the full potential of robotic surgery can be realized. The systems we have now have greatly improved dexterity, and with aerogels the development of the full potential of sensory input can be seen in the near future. Some authors also believe that robotic surgery can be extended into the realm of advanced diagnostic testing with the development and use of ultrasonography,^[21] near infrared and confocal microscopy equipment.

TABLE 3. Current Applications of Robotic Surgery

Orthopedic surgery	Neurosurgery	Gynecologic surgery	Cardiothoracic surgery	Urology	General surgery
Total hip arthroplasty: femur preparation	Complement image-guided-surgery	Tubal re-anastomosis	Mammary artery harvest	Radical prostatectomy	Cholecystectomy
Total hip arthroplasty: acetabular cup placement	Radiosurgery	Hysterectomies	CABG	Ureter repair	Nissen fundoplication
Knee surgery		Ovary resection	Mitral valve repair	Nephrectomy	Heller myotomy
Spine surgery					Gastric bypass
					Adrenalectomy
					Bowel resection
					Esophagectomy

Figure 3; Table 3

There is a whole realm of specialities that robotic surgery can go into (as shown in figure 3). Future advancements are currently being worked on, such as systems to relay ‘touch sensation’ from robotic instruments back to the surgeon. Other laboratories are working on the improvement of current methods and developing new devices for suture-less anastomosis.^[22]

CONCLUSION

To conclude, our investigation has shown that the future of surgery is bright. Not only will we see vast improvements in the operating room but also, through the sophisticated nature of aerogels, precise, accurate and significantly sensitive robotics. This would greatly benefit the majority of surgical procedures, more importantly the more risky and potentially fatal ones. Through advanced robotics the toughest of surgery can become simpler, putting less pressure on surgeons, allowing them to complete procedures with confidence and ease with eliminating possibilities of mistakes.

Nanotechnology is still young; an immense and bright future is still ahead. Furthermore, robotic surgery although a little more advanced, is also in its early stages. Nonetheless it has proven to be great value to conventional surgery. Through Multi-walled Carbon Nanotube aerogels and their important feature of significant sensitivity, robotic surgery is set to change surgery by advancing in surgical procedures and technology. Despite all this, it also has the ability to go further than the limits surgeons have, putting forward the question. Will surgical robotics replace conventional surgery in the future? A definite possibility indeed, but an answer to be told by time.

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