Investigating the Potential Impact of Advanced Robotics on the UK's National Health Service

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Table of Contents

Introduction

The NHS in the UK is an extremely important service. Offering free at the point of consumption health care to all UK citizens, the NHS treats over 1 million patients every 36 hours[1] and performs over 4.7 million surgical procedures per year[2], over 40 percent more than only a decade earlier[3].

Despite this, the NHS faces extreme amounts of cost pressure; in 2016/17, the NHS's total expenditure was reported at £124.212 billion, yet for the same year the NHS had a budget of £120.512 billion[4]. The net deficit of the NHS is projected to continue to persist, at over £3.5 billion per year by 2019/20[5].

For the NHS to continue to provide high-quality free healthcare services in the UK, it needs to look for ways to increase efficiency in the services it offers. A potential solution to this problem is advanced robotics, which if implemented effectively could help support and carry out surgical procedures better than human surgeons and with significant time and cost reductions.

(Refer to Appendix A for an in-depth breakdown of the business model of the NHS)

[1] *Department of Health, 2015*

[2] *Royal College of Surgeons, 2016*

[3] *NHS Digital, 2016*

[4] *HM Treasury, 2017*

[5] *Ibid.*

What is Advanced Robotics?

The Oxford dictionary defines advanced robots as machines capable of carrying out a complex series of actions automatically. McKinsey defines advanced robots as increasingly capable robots with enhanced senses, dexterity, and intelligence used to automate tasks or augment humans.

There is a growing market for advanced robots within healthcare. Markets and Markets estimate that the market for advanced robotics in healthcare will grow to $11.4bn by 2020. Surgical robots comprise the largest component of the medical robotics market[1], with the use of robots to facilitate minimally invasive surgery being the main application currently.

Advanced robots are gaining enhanced senses, dexterity, and intelligence due to advancements in machine learning, artificial intelligence, actuators and sensors[2]. These advances will allow for new types of advanced surgical robots, which will be able to work safely alongside clinicians such as surgeons, and even enable them to interact independently with patients.

Utilising Quid, a leading strategic news and intelligence aggregation platform, it appears that 25% of robotic healthcare companies specialise in surgical procedures, with the largest CAGR in the market (22.1% between 2014-2017). *(Appendix C1).* Regarding patents in the robotic healthcare industry, surgically related applications took the largest proportion of the patents (31%). *(Appendix C2).*

[1] *IndustryArc*
[2] *Please refer to Appendix B*

Potential Criticisms of Advanced Robotics in Surgery

The main objections to implementing advanced robotics into surgical procedures within the NHS are:

- Will individuals even be willing to receive robotic surgery?
- Won't it be very costly to implement?
- What will happen to all the human surgeons?

Will individuals even be willing to receive robotic surgery?

In a 2017 survey by PwC, the UK was the least willing (36%) out of the respondents for robots to perform minor, minimally-invasive surgery. This may seem considerably high – if people are not willing to receive robotic surgery, then there is no point even implementing such technology.

However, out of the 12,000 UK respondents, over a third are still willing. Also, as there were only 12,000 people in the survey, there needs to be some consideration of how well this represents the entire population. This statistic only really tells the degree of today's acceptance of robots in different societies, as the technology develops and the benefit and quality of the technology becomes clear then acceptance will improve, with the current rate still millions of operations per year.

Won't it be very costly to implement?

Studies show that costs associated with current robot-assisted surgery are higher because of longer operating times and expense of equipment (Surj, 2012). A new da Vinci Si® (a robot-assisted surgical system) costs around €1.7 million, plus the yearly maintenance cost of about 10 % of the initial purchase. Cost analysis has been performed (Bolenz et al., 2017) and indicates that current robot-assisted surgery is more costly (1.5 times more) than conventional open surgery.

However, it should be noted that this analysis is based on current costs, and there is a trend of falling setup costs for advanced robots (*Appendix B*). Additionally, current robots such as the da Vinci robotic system have proven they can result in significantly lower blood loss, a lower percentage of postoperative complications, and shorter hospital stays (Surj, 2012), all of which help to reduce overall hospital costs.

What will happen to all the human surgeons?

With the development of advanced robotics, it will become necessary for healthcare professionals to answer the question of what is the unique role of the human? Robots will soon surpass human performance in physical and some decision-making tasks (*Appendix B)*, yet there will still be roles where clinicians are needed. Be it to operate using more advanced robot-assisted devices or to make more obscure case-by-case based decisions, with the robotic systems being directed on the physical tasks they perform.

Applications of Advanced Robotics in Surgery

There are around 2,200 different types of surgical procedures and treatments offered through the NHS, costing an estimated £58 billion in 2016/17 (HM Treasury 2017).
The application areas with the greatest potential benefit from advanced robotics are:

- Minimally invasive procedures, such as:
    - Cataract operations
    - Urological operations

(for further explanation why these are the application areas with the greatest potential, see Appendix D)

Cataract Operations

Current Issues:
Cataract operations cost the NHS £763 to £1,164 per eye per person (Department of Health). There are approximately 330,000 procedures performed each year (Royal College of Ophthalmologists), totalling a cost of £384 million on average for the NHS per year. Cataracts surgery is a relatively simple procedure that usually takes 30 to 45 minutes to perform. Unfortunately, due to minor imprecision by human surgeons, 1 in 1,000 procedures results in permanent sight loss in the treated eyes.

The risk of developing cataracts increases with age. The number of people aged 60 and over is projected to increase from 14.9m in 2014 to 21.9m by 2039 (ONS, 2015). This will put increased strain on the NHS to meet the demand - it is estimated in ten years we will need double the number of surgeons globally carrying out the procedure due to the ageing population.

Solution:
Progress has been made recently in advanced robotics for performing cataracts operations. Axsis is a surgical robot device developed by Cambridge Consultants. It is small and compact and can operate on the eye with greater accuracy than a human. Axsis aims to prevent the risk of human error in cataracts operations, with the robot being equipped with software that ensures certain boundaries are not breached when operational. Chris Wagner, the lead roboticist on the project, claims “It won’t let you make the mistake of punching through the back of the lens,”.

We have already seen the use robot-assisted devices, such as the Da Vinci system, for some eye-related operations. The difference here is that Axsis is extremely compact and with the continued improvement of AI and machine vision, such surgical robots could help support and reduce the pressure of cataracts operation demand on surgeons.

Current prototype assistive robots for this procedure cost approximately £710,000 (MIT Technology Review, 2017), yet with the predicted trend of falling setup costs (*Appendix B*), this cost could fall by as much as 60% in the next seven years. Additionally, with AI advances and the automation of surgical procedures, robotic procedures could be done precisely in a fraction of the time. Therefore, this technology could result in more operations, that are cheaper and more successful, performed by the NHS.

Urological Operations

Current Issues:
There are 1,475 Urology specialist surgeons in the UK, performing 736,500 procedures per year (Royal College of Surgeons, 2016). The average cost of urology operations is £1,975 (Baddow Hospital, 2017). This results in an average total cost for the NHS each year of £1.454 billion.

Solution:
An extensive 2012 study by Rocco et al. concluded that the introduction of robotic assistance in urological surgery would result in shorter hospital stay (3 vs 6 days). Based on analysis conducted by the BBC, it costs on average £400 a day for a bed within the NHS. Based on this analysis*, it follows that implementing advanced robotics to assist procedures could save an average of £800 million per year for the NHS.

Additionally, it is reported (Giri et al., 2015) that, based the current state and predicted development of advanced healthcare robotics[1], urology procedures undertaken by advanced robots would result in less blood loss (200 vs 800 ml) and the mean time of continence postop is projected to be a third of the time (25 vs 75 days). Furthermore, at the 12-month follow-up, the success rate of recovering erectile function from nerve-sparing operations performed by advanced robotics is projected to be 81% compared to the current 49%.

Therefore, certain urology operations (operations not requiring bespoke specialised invasive treatment) could be more time and cost-efficient, as well as more successful, due to the implementation of advanced robotics.

**Even though the study is from 2012 and can be argued to be outdated, it was a very scientific calculated estimate of the efficiency gains from robot assistance which helps illustrate the benefits of advanced robotics in urology.*

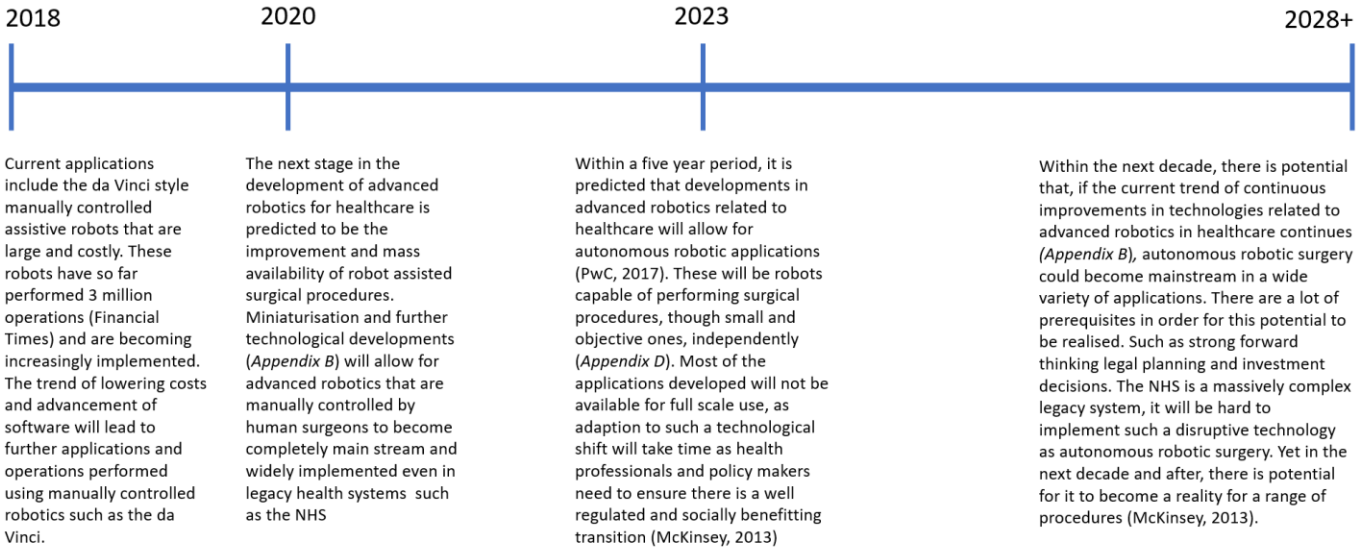
[1]*Refer to Appendix B*

Timeline of expected technological development

Technological advances are hard to predict. Nevertheless, a timeline outlining the general trend of predicted development, based on recent trends (*evidenced in Appendix B*) is illustrated below.

The key takeaways from this model are:

- In the next two years, assistive surgical robots will become more commonplace and continue to have lower setup costs and be used for a wider range of applications.
- In the next five years, advances will allow for the development of more autonomous surgical robots – which after a decade or more, have the potential to become more commonplace in health systems such as the NHS.



According to this model, applications such cataract and urological operations have the potential to be implemented into the NHS by 2020 and have the continued potential to improve and meet the benefits discussed.

Conclusion

Surgical procedures cost the NHS an estimated £58 billion in 2016/17 (HM Treasury 2017). With the growing and increasingly ageing population, there is growing strain on the NHS to find new ways to increase efficiencies and reduce the costs and time associated with surgical procedures. Advanced robotics can provide part of the solution to this problem. This report has illustrated that the implementation of advanced robotics into surgical procedures could result in:

- More efficient, precise and lower costing cataracts operations
- Safer urological operations that result in shorter hospital visits and lower costs

Out of the 2,200 different operations offered on the NHS, there will be many other application areas that could expect similar benefits, including many other minimally invasive procedures that have many parallels to the examples analysed, such as gastrointestinal operations and colonoscopy operations. These two application areas analysed simply show what could be achievable by using advanced robotic technologies to assist, and potentially perform the role of, the surgeon.

As costs of implementing advanced robotics fall and the technologies continue to develop *(Appendix B),* we will see more wide-scale implementation of advanced robotics in healthcare. Advanced robotics will not replace surgeons entirely, but augment their performance and potentially replace them in minor operations that have significant potential for efficiency gains, such as the illustrated examples. This will free surgeons to perform more complex and intricate tasks, and help alleviate the pressure of increased demand for surgical procedures on the NHS. Furthermore, as the technology continues to develop and become more mainstream, public willingness and acceptance will be expected to go up (PwC, 2017), yet as of now it still means millions of potential operations could be supported and improved using advanced robotics.

Word Count: 1964

Appendix A - The NHS's Business Model

Source: www.nhs.uk (2016)

The NHS is a large and intricate organisation. To provide some context and overview into how it functions, here is a description of the NHS broken into the nine blocks of the Business Model Canvas.

NHS England, NHS Wales (GIG Cymru), and NHS Scotland provide the health care services and form the NHS in Great Britain. During this report, "the NHS" will be referring collectively to all three of these institutions. This is because they can all be classified together regarding funding, performance and the services they offer and are simply broken up due to geographical borders.

Customer Segments

Anyone who is a UK citizen has the right to receive the health care services the NHS offers. The services provided differ on an individual basis and are not segmented based on any set of the UK demographics. In that sense, the NHS has a customer base as large and diverse as the UK population. In 2016, UK had a population of 65.6 million; 18.9% 0 to 15 years, 63.1% 16 to 64 years, 18.0% 65 and over. (ONS, 2017)

Value Proposition

The NHS is based on the core principle that *"Good healthcare should be available to all, regardless of wealth".* Leading to the fundamental value proposition that, except for some charges such as prescriptions, the NHS is a free at the point of consumption health service for UK residents.

Channels

The NHS has numerous outlets through which it can reach UK citizens and provide the services it offers, these are:

- Pharmacies
- Clinics
- GP Offices
- A&E
- Ambulance/Paramedic services
- Care services

Customer Relationships

The NHS has numerous outlets through which it engages with UK citizens. These include primary care services such as GP check-ups and consultations, which can lead to referrals that may result in individuals interacting with other services and bodies within the NHS. There is an extensive list of services and bodies that act within the NHS, each directly engaging with citizens on an individual basis to ensure all health needs and problems are dealt with.

Key Resources

The NHS is such a large and resource intensive organisation. In 2016/17 the budget for the NHS was £123.202bn. This budget is required to fund the all of the services the NHS runs, from financing the state of the art medical equipment to employing the 1.5 million employees. Other resources the NHS requires include human capital; the technical skills that the employees of the NHS have that ensure high-quality health services are provided.

Key Activities

The NHS an extensive number of services. These can be classified into the key activities of; medical consultations and referrals, prescribing medication and medical plans, performing medical procedures, responding to emergencies, and check-up and long-term care services.

Key Partnerships

Source: www.england.nhs.uk (2016)

The NHS is an independently acting body of UK Government which has following key partnerships:

Clinical commissioning groups (CCGs):
CCGs are clinically led statutory NHS bodies responsible for the planning and commissioning of healthcare services for their local area. CCG members include GPs and other clinicians, such as nurses and consultants.

Health and wellbeing boards:
Health and wellbeing boards were established by local authorities to act as a forum for local commissioners across the NHS, social care, public health and other services.

Public Health England (PHE):
PHE provides national leadership and expert services to support public health, and also works with local government and the NHS to respond to emergencies.

Vanguards:
Vanguards were introduced in 2015 as part of the NHS Five Year Forward View. The 50 chosen vanguards are tasked to develop new care models and potentially redesign the health and care system.

The NHS is also regulated by external bodies, the primary ones are:

- General medical council
- NHS Improvement
- Health and Care Professions Council
- Care Quality Commission

Revenue Streams

The NHS revenue is the result of public spending, funded primarily from taxation. When the NHS was launched in 1948, it had a budget of £437 million (roughly £15 billion at today's value). For 2016/17, the NHS has a budget of £120.512 billion (HM Treasury, 2017).

Cost Structure

The NHS's expenditure was £124.212 billion in 2016/17 (HM Treasury, 2017). The NHS spends an estimated £45.3 billion on its pay bill of 1.5 million employees. An estimated £17.8 billion a year is spent on medicines while about £58 billion is spent on 2,200 different hospital procedures and treatments, including such common surgery as cataract operations and hip replacements and rarer but expensive treatments such as heart transplants. Additionally, the NHS constantly needs to focus on future growth and development, which leads to expenditure in R&D Innovation and infrastructure development. The overall, revised, deficit (expenditure minus budget) was reported to be £3.7bn for the 2016/17 financial year. (Nuffield Trust, 2017)

Appendix B – Technological advancements in advanced robotics

Advancements in machine learning

Advancements in machine learning include the ability for machines to know undertake what is called "validated learning" – a process which is best illustrated through Google DeepMind's Alpha Go Machine Learning robot. Which beat a top-ranked professional in 2016 and the world's number one in 2017 (MIT Review, 2017). This advancement in machine learning capability in the last two years has opened the potential for more intelligent robotics in the healthcare industry. The world leading machine learning companies, Alphabet Inc. and IBM's Watson division both have dedicated healthcare teams to help continue to advance the machine learning applications for healthcare forward.

Advancements in AI

Advancements in AI include residual neural networks, which allows robotic machine vision to surpass the human-level of performance for image processing. Additionally, natural language processing is allowing machines to read hundreds of pages per second (PwC, 2017), and memory augmented Neural Networks can store facts for later use and surpass the performance of any human in simple knowledge tasks. Here are just a few of the many examples illustrating the current state of AI. All of which were not applicable or even available in any form five years ago, and continue to develop and improve yearly (PwC, 2017).

Advancements in actuators

Advancements in actuators have seen the development of a smart actuator which was incorporated into the design of intelligent autonomous robotics (Seok-Jo, 2015). In the last two years, the technology of smart actuators has continued to improve, allowing for smart robotics to be applied to more complex tasks, such as in healthcare.

Advancements in sensors

Advancements in sensors are best illustrated through the increased improvement in IoT (sensor) technology. It is reported that the number of intelligent sensors increased 31% from 2016 to 8.4 billion in 2017. Experts estimate that the IoT will consist of about 30 billion objects by 2020, with an estimated global value of $7.1 trillion by 2020 (Hsu et al. 2016). With increased growth in this area, further improvements and developments will result in the performance of sensors and their applications, such as in healthcare.

Falling setup costs

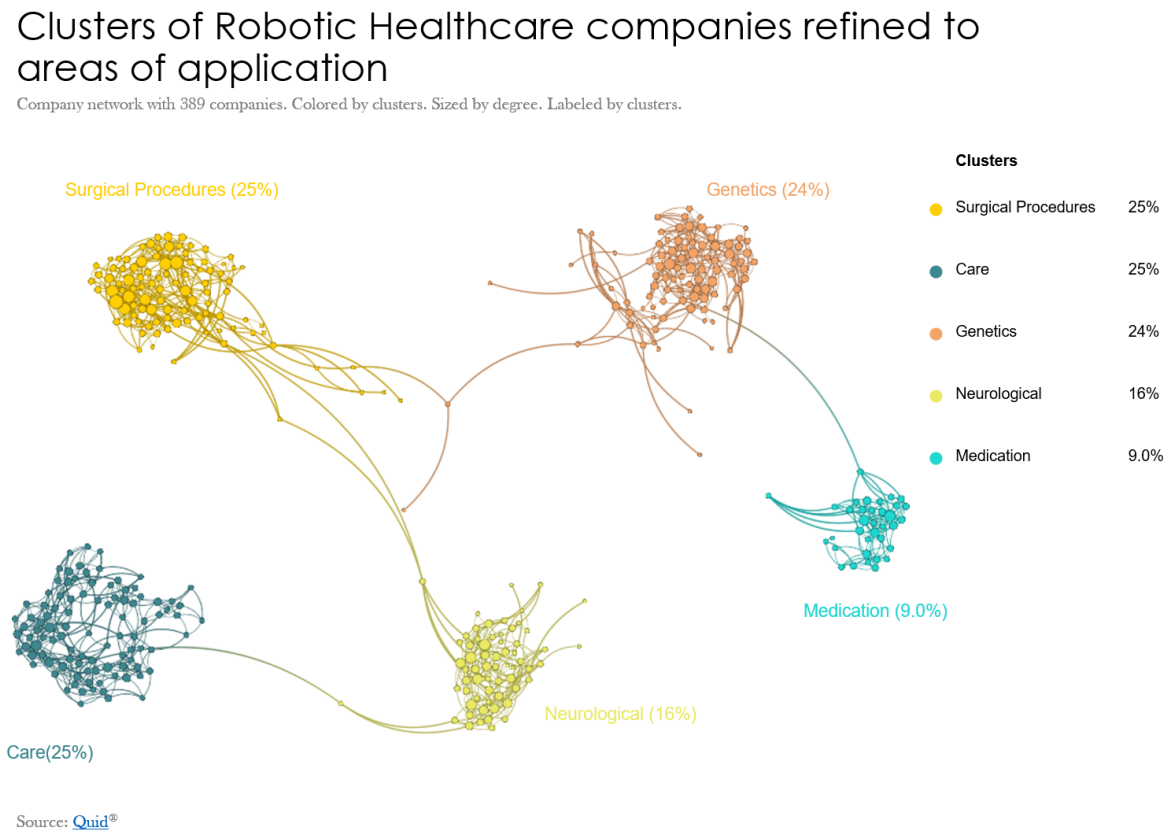
The setup costs for advanced assistive robots (such as the current da Vinci device) will drop, on average, by approximately 65%, by 2025 (ARK Invest, 2017). Predicted due to continued advances in technologies that allow for miniaturisation, and lower costs of mass-scale production and resourcing for advanced robotics.

Appendix C– Quid Analysis

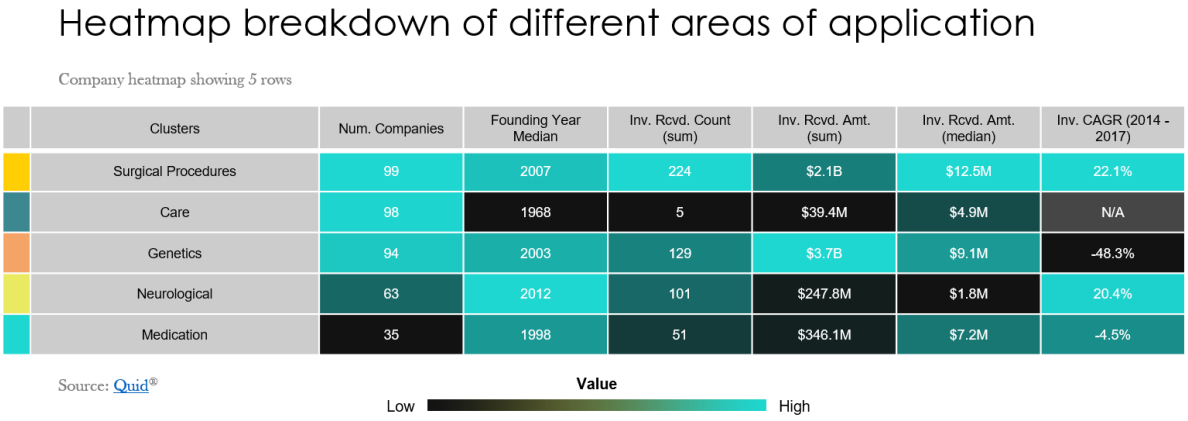
C1: Companies in the robotic healthcare industry

The search conducted: **("robotics" OR "robot" *) AND ("health" OR "health care" OR "medical")**

The search was conducted February 13th, 2018; there were no restrictive search filters applied.



Notice that 25% of robotic healthcare companies specialise in surgical procedures



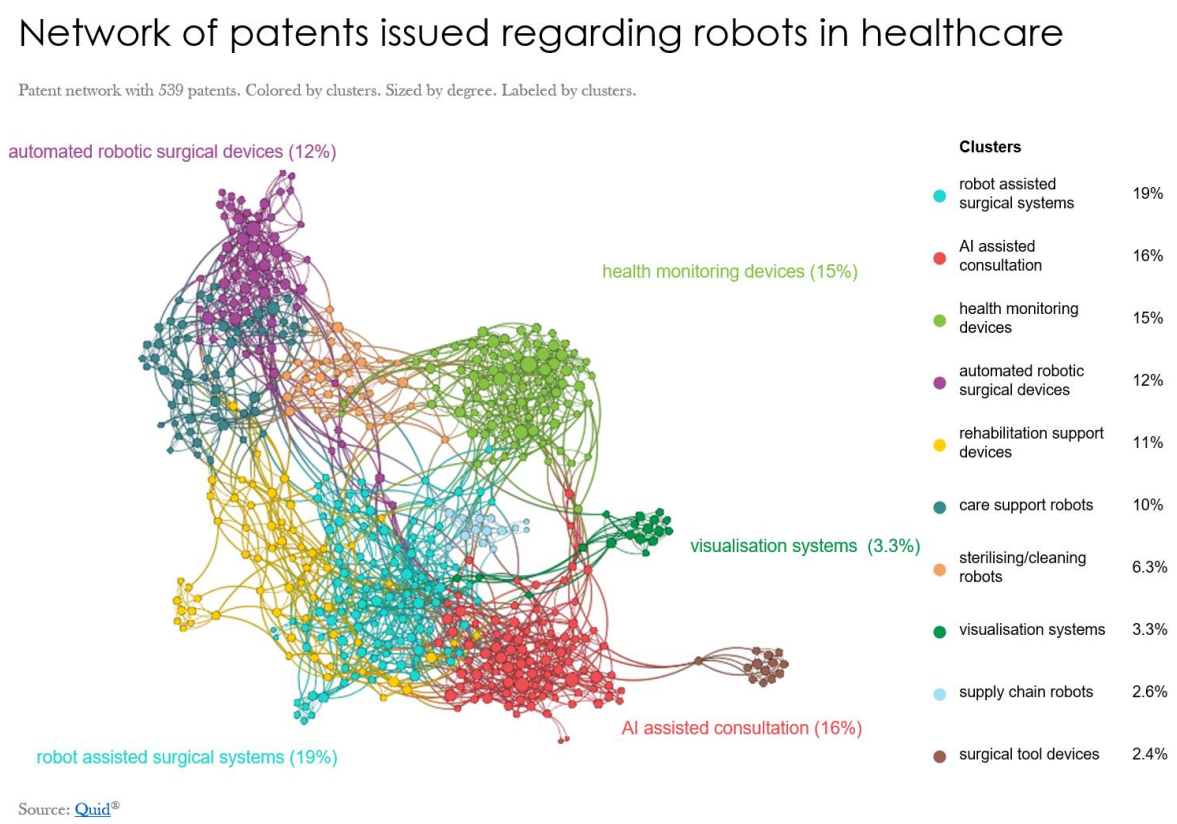
Clusters	Num. Companies	Founding Year Median	Inv. Rcvd. Count (sum)	Inv. Rcvd. Amt. (sum)	Inv. Rcvd. Amt. (median)	Inv. CAGR (2014 - 2017)
Surgical Procedures	99	2007	224	$2.1B	$12.5M	22.1%
Care	98	1968	5	$39.4M	$4.9M	N/A
Genetics	94	2003	129	$3.7B	$9.1M	-48.3%
Neurological	63	2012	101	$247.8M	$1.8M	20.4%
Medication	35	1998	51	$346.1M	$7.2M	-4.5%

Notice that surgical procedures constitute the largest CAGR in the market and the second highest total investment amount

C2: Patents in the robotic healthcare industry

The search conducted: **(robot*) AND (health OR healthcare)**

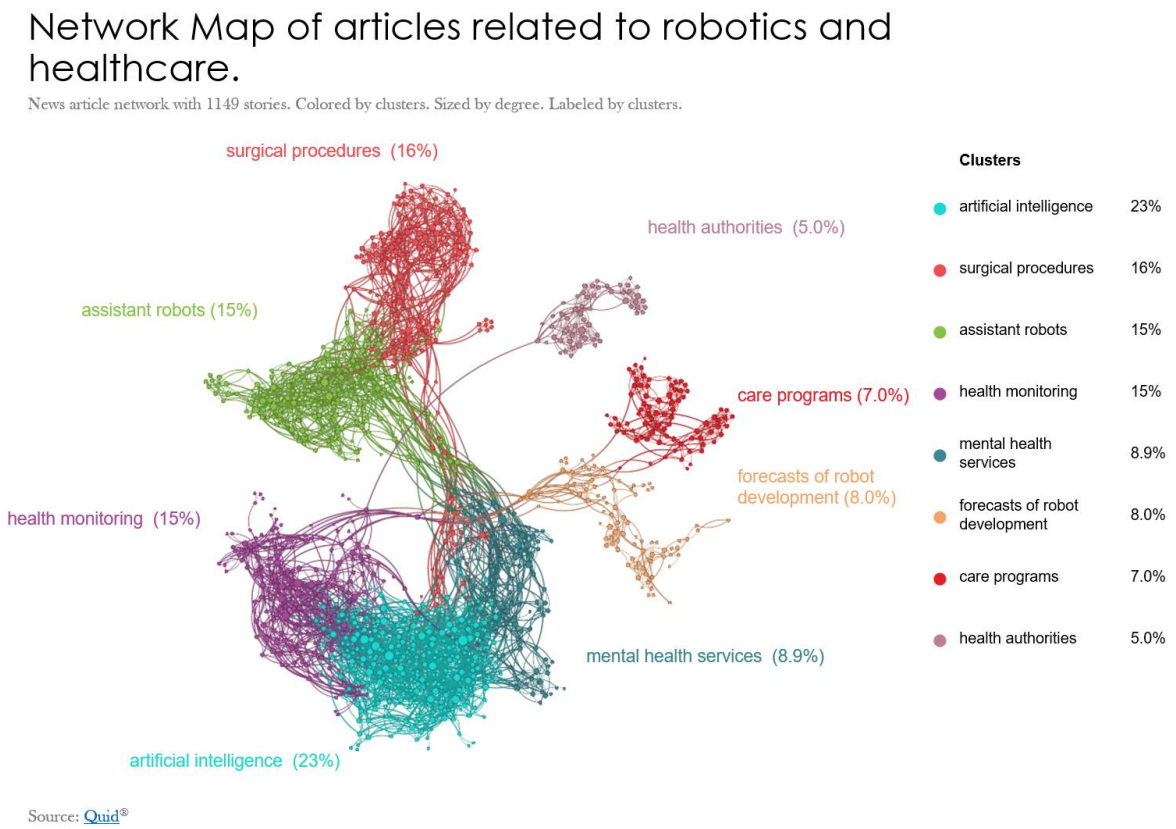
The search was conducted 28th March 2018, restricted to a 5-year period from the search date.



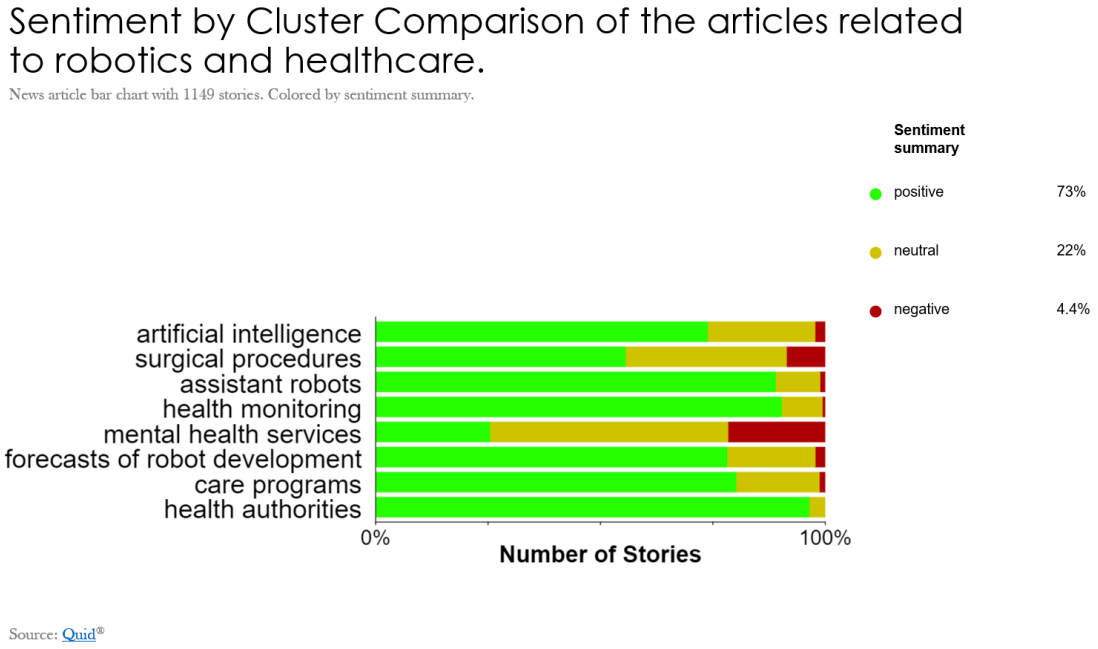
Notice that surgically related applications took the largest proportion of the patents (the sum of the automated robotic surgical devices and the robot-assisted surgical systems clusters).

C3: Articles related to both robotics and healthcare

The search conducted: **robot * AND (health * OR healthcare)**
The search was conducted 28th March 2018, restricted to a 2-year period from the search date.



Notice that surgical procedures were the second most talked about topic.



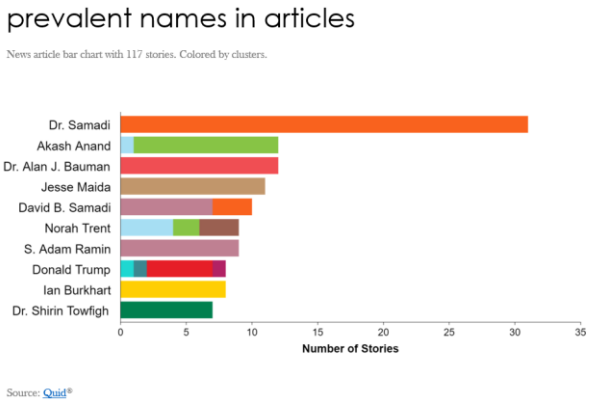
Notice that the topic surgical procedures have a 12% negative and 33% neutral sentiment. This can be associated with the unwillingness of the public in undergoing surgical procedures from robots – which is 36% in the UK according to a 2017 PwC survey.

Appendix D – Application areas of advanced robotics in surgery

Utilising the research and Quid searches undertaken helped derive insights into where to direct the analysis.

The above Quid searches highlight that advanced robotics in surgical procedures is of significant potential - 25% of robotic healthcare companies specialise in surgical procedures, with the largest CAGR in the market (22.1% between 2014-2017). As well as 31% of patents in the robotic healthcare industry being related to surgical applications.

Additional Quid analysis helped direct the focus within the space of surgical applications. For example, when analysing the news and articles database, the most popular name mentioned within the articles was Dr B. Samadi. Dr Samadi is head of urology and chief of robotic surgery at Lennox Hill Hospital, this directed me into researching applications into urology for advanced robotics and uncovering numerous research papers that highlighted to potential benefits of implementing such technology.



Collating all the background research together allowed for the collection and classification of all of the application areas and examples, to understand where the best application area was for the NHS to focus.

List of current companies developing advanced robotics for the healthcare industry:

From the above quid analysis and extensive research, we can define the categories of applications as follows. This report focuses on the application of **Surgical Assistants** and the potential use of **Autonomous Surgeons**, due to the research conducted illustrating promising advances (technological advances and increasing business activity) in this application area.
The classification areas are defined below, ranked by the number of independent examples found:

1. Surgical Assistants
These robots assist surgeons with performing operations, typically minimally invasive procedures. The surgeon can view and guide the robot in procedures, controlling the mechanical arms of the robot in a very precise and efficient manner. More advanced 3DHD technology gives surgeons the spatial visualisation and analysis needed for highly complex surgery, making this the most rapidly growing area of smart robotics in healthcare.
2. Autonomous Surgeons (potential use*)
With further advances in the technologies required for advanced robotics to perform complex tasks independently, a new category may arise in healthcare applications. One where the robot does not assist the surgeon, but carries out the task independently and not directly guided, freeing the surgeons to perform other tasks or relieving the stress of increased demand for procedures.

3. Rehabilitation Robotics
These robots can help augment and support the recovery period for patients, allowing for improved mobility, strength, coordination, and quality of life. These robots can be programmed to adapt to the condition of each patient as they recover from strokes, traumatic brain or spinal cord injuries etc.
4. Telepresence
This is where the robots would act as the eyes and hands of the doctors, operating via remote access from a different location. “Specialists can be on call, via the robot, to answer questions and guide therapy from remote locations,” (Keefe, 2017).
5. Care Support Robotics
These are robots whose role is to aid and comfort to people suffering from not only physical impairments but mental disabilities and loneliness. They can interact with the individuals and help augment their abilities to allow them to have a high quality of life and provide reassurance
6. Medical Transportation Robotics
Supplies, medications, and meals and other resources can be delivered efficiently to patients and staff by these robots. This ensures that needs of where resources are required can be met more effectively, and the internal resource allocation can be optimised through the transportation resources based on robotic systems.
7. Hygiene Robotics
Healthcare facilities can now use robots to clean and disinfect surfaces. These are robots that can navigate and clean and precisely disinfect a room of Hospital Acquired Infections (HAI) and other dangerous infections such as MRSA.

Below is a tabulated list of the 98 companies researched that are currently operating in the advanced robotics healthcare industry, defined by the classification group:

	Surgical related
	Minimally invasive surgery related
	Rehabilitation Robotics
	Telepresence
	Care Support Robotics
	Medical Transporation Robotics
	Hygiene Robotics

Company	Company Description	Company	Company Description
Auris Surgical Robotics, Inc.	Auris Surgical Robotics, Inc. develops robotics technology for medical applications. The company designs novel dual-arm microsurgical system for ophthalmic surgery.	MedTech Société Anonyme	Medtech Société Anonyme designs, develops, and markets surgical robots. The company offers ROSA robotic device to enhance the safety and reliability of various neurological procedures without compromising established surgical protocols
Iowa Precision Robotics Ltd.	Iowa Precision Robotics Ltd. develops medical robot platform for robotic surgery, which combines a range of patented technologies benefiting surgeons and patients.	Blue Belt Technologies, Inc.	Blue Belt Technologies, Inc. develops and commercializes robotics-assisted technologies for use in orthopedic surgery and other specialties.
Medrobotics Corporation	Medrobotics Corporation manufactures and markets robotic surgical products. It offers Flex robotic system, a robot-assisted platform that provides surgeons to access and visualize hard-to-reach anatomical locations.	MAKO Surgical Corp.	MAKO Surgical Corp., a medical device company, markets its advanced robotic arm solution, joint specific applications for the knee and hip, and orthopedic implants for orthopedic procedures in the United States and internationally.
Stereotaxis, Inc.	Stereotaxis, Inc. designs, manufactures, and markets robotic systems and instruments for the treatment of abnormal heart rhythms in the United States and internationally.	Medrobotics Corporation	Medrobotics Corporation manufactures and markets robotic surgical products. It offers Flex robotic system, a robot-assisted platform that provides surgeons to access and visualize hard-to-reach anatomical locations.
Acrobot	Acrobot provides precision surgical systems for computer-assisted 3D planning, surgical navigation and surgeon-controlled robotic surgery.	SurgiQuest, Inc.	SurgiQuest, Inc. manufactures and markets medical devices for minimally invasive surgery in the United States and internationally.
PRAXIM Medivision S.A.	PRAXIM Medivision S.A. develops computer-assisted medical robotic equipment and software for full knee and hip replacement.	M.S.T. - Medical Surgical Technologies, Ltd.	M.S.T-Medical Surgical Technologies Ltd. manufactures and distributes medical equipment. The company offers image guided laparoscopy solutions.
Dextera Surgical Inc.	Dextera Surgical Inc. designs and manufactures proprietary stapling devices for minimally invasive surgical procedures in the United States, Japan, Germany, and internationally.	Endocontrol SA	Endocontrol SA designs, manufactures, and markets robotic assistance solutions for laparoscopic surgery.
Simbionix USA Corporation	Simbionix USA Corporation provides simulation, training, and education solutions for medical professionals and the healthcare industry.	Think Surgical, Inc.	Think Surgical, Inc. develops, manufactures, and markets image directed surgical robotic systems for orthopedic surgeries.
Z-KAT, Inc.	Z-KAT, Inc. is a holding company which through its subsidiaries develops and markets therapy-focused medical solutions for minimally invasive surgery.	Physcient, Inc.	Physcient, Inc. manufactures Differential Dissector, a surgical instrument for blunt dissection.
OMNI life science, Inc.	OMNI life science, Inc. designs, manufactures, and distributes implants, instrumentation, and solutions for joint replacement orthopedics.	Omni Orthopaedics Inc	Omni Orthopaedics Inc., through its subsidiaries, designs, develops, and manufactures medical devices for the orthopedic industry.
Mazor Robotics Ltd.	Mazor Robotics Ltd., together with its subsidiaries, engages in the development, production, and marketing of medical devices for supporting surgical procedures in the fields of orthopedics and neurosurgery in the United States and internationally.	Neocis Inc.	Neocis Inc. manufactures and markets robotic guidance system for dental implant procedures.
Novadaq Technologies Inc.	Novadaq Technologies Inc. develops, manufactures, and markets fluorescence imaging products for use by surgeons in the operating room and other clinical settings in the United States and internationally.	NovaTract Surgical, Inc.	NovaTract Surgical, Inc., a medical device company, focuses on developing solutions for improving current practices in minimally invasive surgery.
OmniGuide, Inc.	OmniGuide, Inc. develops advanced energy surgical products for minimally invasive surgery, laparoscopy, and robotic-assisted surgery applications.	Synaptive Medical Inc.	Synaptive Medical Inc. develops and supports integrated systems and solutions that combine informatics, imaging, surgical planning, navigation and advanced optics, to solve challenges both in and beyond the operating room through collaboration with surgeons and hospitals.
Restoration Robotics, Inc.	Restoration Robotics, Inc., a medical device company, develops and commercializes image-guided robotic systems in the United States and internationally.	Epica International, Inc.	Epica International, Inc. designs, develops, and distributes progressive robotic systems.
Hansen Medical, Inc.	Hansen Medical, Inc. develops, manufactures, and sells medical robotics designed for the positioning, manipulation, and control of catheters and catheter-based technologies in the United States and internationally	FlexDex Inc.	FlexDex Inc. operates as a minimally invasive surgery (MIS) device or laparoscopic device platform company.
Cambridge Medical Robotics Limited	Cambridge Medical Robotics Limited, a medical devices company, focuses on developing robotic systems for minimal access surgery applications.	Riverfield, Inc.	Riverfield, Inc. develops surgical support robotic systems for the healthcare industry. The company was founded in 2014 and is based in Tokyo, Japan.
KASPAR	a child-sized humanoid robot designed to help teachers and parents support children with autism	AVRA Medical Robotics, Inc.	AVRA Medical Robotics, Inc. develops and manufactures medical surgical devices. It develops a medical robotic system for minimally invasive surgical facial corrections in partnership with the University of Central Florida.
Giraff	a mobile communication robot that facilitates a chronically ill patients' contact with the outside world	TransEnterix	a medical device company, it is pioneering the use of robitcs to improve minimally invasive surgery. They are developing and commercialising its ALF-X system, a multi-port robotic surgery system that enables up to four arms to control robotic instruments and a camera, and its SurgiBot system, a single-incision, patient-side robotic-assisted surgery system.
Bestic	a robotic-assisted dining appliance for people who are unable to move their arms or hands	Titan Medical	is a development stage company that is developing its SPORT surgical system composed of a sugeon-controlled robotic platform with 3D vision and interactive instrument control for performing minimally invasive surgery. The company believes sport will enable surgeons to perform procedures within small-to-medium-size surgical spaces for general abdominal, gynecologic, and urologic indications.
Toyota	four robots that enable immobilized patients to walk and balance	Hansen Medical	develops, manufactures and sells medical robotics designed for the positioning, manipulation, and control of catheters. The company's Magellan Robotic System controls the proprietary Magellan Robotic Catheter eKit and a few days later, the company announced its first clinical procedure with the Magellan in the US.

Xenex	robots that dinfect hospital facilities using UV light, reducing HAI's	Stereotaxis	designs, manufactures, and markets robotic systems and instruments for the treatment of abnormal heart rhythms. Its products include the Niobe ES robotic system and Vdrive system. Stereotaxis has stategic alliances with Siemens and Phillips Medical Systems.
Aethon's TUG	robots that automate the delivery and transportation of the immense amount of materials moving throughout hospitals daily	Verb Surgical	is working with Johnson & Johnson's Ethicon and Alphabet Inc's Verily to develop the generation of surgical robots, incorporating advanced visualisation, machine learning, data analytics and connectivity
Veebot	a robot that can draw blood faster and more safely than a human	Mazor Robotics Renaissance	surgical guidance system transforms spine surgery from freehand procedures to guided procedures.
Pipeline Biomedical Inc.	Pipeline Biomedical, Inc. engages in the research, development, manufacture, sale, and distribution of orthopedic implants. It offers adult reconstructive total joint implants for hip, knee, and shoulder applications	Aba Inc.	Aba Inc. engages in research and development and manufacturing of robotic medical equipment for patient excrement detection. It manufactures Helppad, which are patient beds equipped with smell sensors for detecting excrement and notifying timings
TrueMotion Spine Inc.	TrueMotion Spine, Inc., a medical device company, commercializes patented cervical and lumbar prosthetic disc replacement devices to preserve and restore motion to the human spine.	Simulated Environment Concepts	Simulated Environment Concepts, Inc. engages in the development and manufacture of medical, health, and wellness equipments in the United States and internationally. Its products include SpaCapsule, a robotic massage therapy system used for medical rehabilitation, relaxation, weight loss,
Fourth State Medicine	They are working with their partners to develop a revolutionary new imaging technology that will deliver the tools surgeons want in order to improve scar reduction and limit the removal of viable and good tissue.	Pong Robotics	Social health and fitness robotics for an aging baby boomer. Robotic solutions to support health, and independent living.
Robotics Design	Robotics design is a manufacturer of industrial modular robots,cleaning robots, robotic arms and manual ergonomic arms.	St Thomas Rutherford Hospital	Saint Thomas Rutherford Hospital owns and operates a hospital that serves patients in the Rutherford County. It offers aortic center, bariatrics and weight loss, behavioral health support
EurEyeCase	EurEyeCase combines cutting edge European robotic technology and creates an integrated setup for vitreoretinal eye surgery.	Mills-Penisular Health Services	Mills-Peninsula Health Services operates as a not-for-profit health care organization in San Mateo County. The company operates a general acute-care hospital; and a medical center that provides a range of outpatient services, including surgery, rehabilitation, and diagnostics
invendo medical GmbH	Invendo medical GmbH develops, manufactures, and distributes sterile, single-use, and light-weight robotically-assisted HD endoscopy products for the field of gastroenterology and GI surgery.	CHI St. Luke's Health Memorial	CHI St. Luke's Health Memorial operates hospitals in Lufkin, Livingston, and San Augustine. It offers cancer and cardiac rehabilitation, cardiac imaging, cardiovascular and stroke, education, dialysis, emergency, express labs, heart and vascular imaging, heart and vascular mobile imaging
Surgerii	Surgerii grasp the third generation of surgical robots to perform safe and reliable, quick operation of the single-lens surgery robot, to improve the operation of doctors	Kettering Adventis HealthCare	It offers health care services in the areas of assisted living, back pain, bariatric, and rehabilitating support services
AVRA	The Company plans to meet the needs of the growing demand for practical medical robotic devices, focusing on the Dermatology field.	Sparrow Health System	Sparrow Health System, Inc. operates healthcare facilities in Michigan. The company offers behavioral health, food and nutrition, and hospice care services
Community Memorial Health System	family-practice health centers that serve communities in Ventura County, California, and beyond. It offers services in the areas of bariatric weight loss, breast care, and cancer	OhioHealth Corporation	OhioHealth Corporation operates a family of not-for-profit, faith-based hospitals and healthcare organizations to serve patients in central Ohio. Its inpatient/outpatient services include behavioral health, and physical rehabilitation programs
Paintsville Hospital Company	Paul B. Hall Regional Medical Center, operates as a primary healthcare facility in Eastern Kentucky. It offers services in the areas of critical care medicine, diabetes care, digestive care (gastroenterology), emergency medicine center, endocrinology, eye care (ophthalmology)	MT Robot	MT Robot is the AGV Systems for manufacturing and healthcare. Transporting resources internally in medical facilities
Cardiovascular Provider Resources	It offers coronary angiography, angioplasty, coronary stenting, and electrophysiology, clinical cardiology consultation, diagnostic cardiovascular testing, research studies	Redviking Group	Redviking Group, LLC designs, manufactures, and sells custom machines and production lines in the United States and internationally. The company offers custom weld and assembly stations, robotic vision inspection systems, and complete assembly lines
Mission Hospital Regional	The company offers asthma, behavioral health, chemical dependency, diabetes education, endoscopy, emergency, laboratory, mission outpatient testing, orthopedics and rehabilitation	Web GmbH	Weber GmbH offers products, software, component parts, and machines for automotive, medical technology, and household appliance industries. It offers solutions in the areas of development and construction, such as product protection with analysis and calculation tools, product development, project management, package inspections
Forest Park Medical Centre	It provides da vinci robotic, esophyX, bariatric, orthopedic, spine, plastic, gynecology and oncology, urology, gastroenterology and endoscopy, otolaryngology	Edgewater Automation	Edgewater Automation, LLC engages in the design, build, and implementation of custom automation equipment. It offers custom automated assembly and test equipment. The company also involves in integration with suppliers of robotics, motion control, and vision systems
St Francis Hospital	St. Francis Hospital, Inc. operates a community hospital that provides inpatient, outpatient, and emergency room services. The company offers medical services, including addiction and mental health care	CPA Group SA	CPA Group SA, through its subsidiaries, provides industrial engineering solutions for photovoltaic solar, semi-conducting, watch making, medical, and other sectors. It is involved in the design and control of miniaturized robotic systems, such as high-precision robots, flexible feeders
Fort Smith HMA	It offers behavioral health, boreham emergency, cancer care, cardiology, critical care medicine, dermatology, and diabetes care	Meikle Group	Meikle Group, Inc., through its subsidiaries, designs and manufactures automated machines and equipment for the automotive and medical industries. It offers cells, robotic-based assembly solutions, vision systems, ultra high precision assembly and test machines, and machine control software.

Infirmary Health System Inc.	It offers industrial medical clinics services, such as injury care, pharmacy, laboratory, digital X-ray, electronic medical records, drug and alcohol testing, case management, extensive physician referral network	WiTricity Corporation	WiTricity Corporation designs, develops, manufactures, and commercializes wireless power solutions based on magnetic resonance technology.
SmartMedical Corp.	Smartmedical Corp. develops urban medical platforms inside and near railway stations for patients, communities, and doctors. Its platforms function as primary care clinics for preventive medicine and general outpatient care	Beijing Nortom Technology	Beijing Noitom Technology Limited develops sensor-based motion capture systems. It offers its systems for visual effect and animation, virtual reality and gaming, sports and fitness, health and medical
Restin	Restin massage chairs gives anyone an on-demand massage therapy, in their living room, every day. Restin provides robotic massage chairs specifically designed for experiential marketing applications.	Softbank Robotics Europe	SoftBank Robotics Europe SAS designs and manufactures kindly and interactive humanoid robots. The company offers robots for education, research, and healthcare
Wyless Inc.	Wyless Inc. provides data connectivity and managed Internet of Thing services for Fortune 500 companies and startups worldwide. It offers global connectivity solutions	VisoSpace	Visospace brings intuitive touch, feel and control into digital spaces including virtual reality and tele-presence.
Behaviour Labs	Behaviour Labs is an innovative startup specialized in robotics, virtual and augmented reality, in the health and welfare sectors.	Angeletoni Industrie	Angelantoni Industrie S.r.l., along with its subsidiaries, engages in biomedical, testing, and clean technologies businesses
ManoMotion AB	ManoMotion AB is a computer vision based software company in Sweden. The company develops a SDK for application developers to implement touch-less interaction	Blue Ocean Robotics	Blue Ocean Robotics ApS, through its subsidiaries, designs, develops, and commercializes robotic solutions. It offers logistic, cleaning and disinfection applications
Thalmic Labs Inc.	Thalmic Labs Inc. develops human-computer interaction technologies that bridge the gap between man and machine.	Bio-Strategy Limited	Bio-Strategy Limited implements distribution technology solutions for research, biotechnology, clinical diagnostics, and industrial applications.
NERVteh	R&D company specialized in simulations focusing on biometric and cognitive driver evaluation, machine learning and data integration.	RoboSoft SA	ROBOSOFT SA designs, manufactures, and sells B2B service robots. The company offers indoor mobile robots that are used for transportation in industries such as healthcare
		Sealed Air Corporation	Sealed Air Corporation provides food safety and security, facility hygiene, and product protection solutions worldwide.

This research of companies and application areas lead to the understanding that the most promising application area is **Minimally Invasive Surgical Procedures.** Due to the number of companies and amount of investment they have received in developing advanced robotics in this area, and the technological advancements of recent years in this application area which allow for the prospect of effective and low-cost solutions.

Within the application of minimally invasive surgical procedures, the areas where sufficient successful progress has already been made include **cataracts surgery** and **urological operations**. Therefore, the analysis included in this report is focused on these two application areas to illustrate the benefits and impacts the NHS can realistically expect from advanced robotics in the shortest time span possible.

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