# BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

## FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

## DEPARTMENT OF FOREIGN LANGUAGES
ÚSTAV JAZYKŮ

# MEDICAL ROBOTICS
ROBOTIKA V LÉKAŘSTVÍ

**BACHELOR'S THESIS**
BAKALÁŘSKÁ PRÁCE

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# Bakalářská práce

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**Ročník:** 3 **Akademický rok:** 2019/20

**NÁZEV TÉMATU:**

## Medical Robotics

**POKYNY PRO VYPRACOVÁNÍ:**

Popište a analyzujte nejnovější pokrok robotiky v lékařství včetně vývoje a programování robotů a diskutujte jejich možné aplikace.

**DOPORUČENÁ LITERATURA:**

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# Abstract

Medical robotics is an area of robots used in medicine and its main purpose is to provide assistance and expand the capabilities of medical personnel. It is also used to help and assist patients and the elderly who are dependent on the help of others. Although it is still a very young field, medical robotics has changed the way in which medicine has been perceived in the last few decades. Due to its high accuracy and ability to help people, its potential is enormous. Specialists and developers are therefore trying to further expand and improve this area. The aim of this work is to provide a comprehensive survey of medical robots' evolution including concrete examples of robots that are used in this area and to explain how individual robots work and how some of them are programmed.

# Key words

medical robotics, minimally invasive, operating theatre, programming, assistance, Heartlander, Xenex, da Vinci, telepresence

# Abstrakt

Lékařská robotika je oblast robotů používaných v medicíně a jejím hlavním účelem je poskytovat pomoc a rozšiřovat možnosti zdravotnického personálu. Dále se používá pro pomoc a asistenci pacientům a starším osobám, kteří jsou závislí na pomoci druhých. I když je to stále velmi mladý obor, lékařská robotika změnila způsob, jakým je medicína vnímána v posledních několika desetiletích. Díky jeho vysoké přesnosti a schopnosti pomáhat lidem je jeho potenciál obrovský. Specialisté a vývojáři se proto snaží tuto oblast dále rozšiřovat a zlepšovat. Cílem této práce je poskytnout komplexní přehled vývoje robotů používaných v medicíně, uvést konkrétní příklady robotů, které se v této oblasti používají, a vysvětlit, jak jednotliví roboti fungují a jak jsou někteří z nich naprogramováni.

# Klíčová slova

Lékařská robotika, minimálně invazivní, operační sál, programování, asistence, Heartlander, Xenex, da Vinci, telepresence

# Rozšířený abstrakt

Uplatnění robotů v lékařství je jedno z nejužitečnějších, jelikož disponují možností práce bez vyčerpání a poskytují bezpečnější a levnější zákroky pro pacienty. Robotika se za posledních pár desetiletí rapidně posunula kupředu, což má za následek celkové zlepšení výsledků prováděných zákroků a rychlejší rekonvalescenci pacientů bez jakýchkoliv následků. Roboti dále poskytují možnost pohybu a osamostatnění se lidem, kteří jsou závislí na pomoci druhých. Cílem této práce bylo vytvořit souhrnný přehled robotů používaných v medicíně, popsat jejich postupný vývoj, možné využití, programování a diskutovat jejich možné aplikace a nejnovější pokroky v tomto odvětví. K zjištění potřebných informací byla využita zejména odborná literatura, vědecké články a další odborné publikace.

Práce je strukturovaná do pěti hlavních kapitol. V úvodu práce je vysvětleno, co je to robotika v lékařství, které typy robotů spadají do tohoto odvětví a jak může být člověku využití těchto robotů prospěšné a nápomocné. Druhá kapitola nastiňuje počátky slova robot a popisuje tři základní zákony, kterými se robot musí vůči člověku řídit. V druhé části kapitoly je zmíněn začátek postupného využívání robotů v různých odvětvích. Poslední část druhé kapitoly je zaměřena na prvního robota používaného v lékařství (Puma 560), který je zároveň jakýmsi předchůdcem mnoha medicínských robotů používaných dodnes.

Třetí kapitola tvoří největší část této práce a je zde popsáno šest konkrétních robotů, kteří patří mezi nejuznávanější a nejlepší roboty v medicíně na světě. Robot da Vinci, který je pojmenován po Leonardu da Vincim je v současnosti nejpoužívanějším robotem na minimálně invazivní operace. Tento robot rozšiřuje možnosti doktorů a umožňuje jim provádět komplexní operace, které nebylo možné před da Vinci robotem uskutečnit. Gamma Knife a CyberKnife jsou roboti využívaní zejména pro léčbu nádorů. CyberKnife je více komplexnějším robotem v porovnání s Gamma Knife, jelikož je schopen léčit nádory po celém těle. Gamma Knife se zaměřuje konkrétně na léčbu nádorů v hlavě. Oba roboti využívají záření, které je během zákroku soustředěno na postižené místo, a s milimetrovou předností dané místo léčí. Dále jsou v práci popsány jednotlivé části obou robotů a jejich konfigurace na operačních sálech. Xenex Germ-Zapping robot je dalším robotem. Tento robot zbavuje operační sály, koupelny, vybavení pokojů, pohotovostní místa a další prostory běžně používané pacienty plísní, virů a mikrobakterií a chrání tak pacienty, personál nemocnice a rodinné příslušníky před potencionálními nemocemi. Xenex Germ-Zapping robot vyzařuje ultrafialové světlo a zabíjí tak všechny bakterie, které nelze zabít pomocí

běžných čistících prostředků. Telepresence Robot, který umožňuje vzdálenou komunikaci mezi pacientem a lékařským personálem je dalším robotem podrobně popsaným v této práci. Tento robot je tvořen dvěma hlavními částmi: Workstation, což je místo, ze kterého je telepresence robot ovládán a telepresence robot, který se nachází v blízkosti pacienta. Posledním zmiňovaným robotem v této kapitole je Yomi. Tento robot je využívaný v zubním lékařství, kde napomáhá zubařům při zákrocích vyžadující přesnost. Yomi využívá tzv. haptické vedení, které vede ruku zubaře při zákroku a eliminuje tak potenciální chyby nebo třes rukou.

Čtvrtá kapitola je zaměřena na budoucnost medicínských robotů a jejich možné využití. Jsou zde popsány pokroky, které byly v posledních letech dosaženy, konstrukce robotů, možnosti jejich navigace, řízení a výroba energie potřebná pro jejich fungování. Konkrétně robot HeartLander, který je schopen pohybu po srdci pacienta, provádět minimálně invazivní operace a umožňuje doručení medikamentů na konkrétní místo na lidském srdci. Mezi roboty budoucnosti patří také Sophia neboli robot s lidskou tváří. Tento robot patří mezi nejvyspělejší roboty v oblasti Humanoidů a v budoucnosti bude nápomocen lidem zotavujících se z operací nebo na odděleních pro děti či seniory. Posledním robotem budoucnosti je nanorobot. Tento robot bude díky jeho snadnému zavedení do lidského těla nezbytnou součástí diagnostiky. Dále může být nápomocen například při procesu hojení nebo léčbě nádorů, jelikož bude schopen aplikovat medikamenty na postižené místo v lidském těle. Podle expertů je budoucnost nanorobotiky v medicéně velice slibná, jelikož existuje mnoho možných aplikací a využití. Závěr práce je zaměřen na roboty určené pro starší lidi, nebo pro osoby s omezenou schopností pohybu. Robot WAD (Walking Assist Device) je robot určen pro pomoc při chůzi osobám s omezenou schopností pohybu a je popsán v úvodu poslední kapitoly. Díky jeho pohodlnému uchycení, motoru umístěného v jeho konstrukci a baterií s velkou kapacitou je WAD ideálním robotem pro podporu chůze. Dalšími roboty jsou mobilní skútr a poháněný invalidní vozík. Tyto stroje nejsou typickými roboty, ale s jejich vylepšeními v posledních letech jako například možnosti programování nebo pohybu pomocí joysticku je možno je zařadit do kategorie robotů. Posledními roboty jsou ASRO a Care-O-Bot. Jedná se o roboty určené především pro starší a nemohoucí lidi. Tito roboti jsou schopni uchopení předmětu a dovezení jej na požadované místo čímž usnadňují lidem práci. Ovládání ASRO robota a Care-O-Bota je skrze tablet, nebo chytrý telefon.

Na základě zjištěných údajů je možné říct, že je zde velmi malá šance, že u jakéhokoliv

zákroku, který v budoucnu podstoupíte, nebude figurovat žádný robot. Z této práce je dále patrné, že robotika a medicína jsou dvě velice úzce spjatá odvětví, která se navzájem doplňují a posouvají jakési imaginární hranice toho, čeho je schopen člověk s pomocí robotiky dosáhnout.

## Klíčová slova

Lékařská robotika, Heartlander, Xenex, da Vinci, telepresence, ASRO, WAD, HeartLander, Sophia, CyberKnife, Puma 560, Yomi, nanorobotika, Care-O-Bot, minimálně invazivní, humanoid

Herman, M. (2020). *Medical Robotics.* Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií. 44 s.

Vedoucí bakalářské práce: Mgr. Ing. Eva Ellederová.

Odborný konzultant bakalářské práce: prof. Ing. Jaroslav Boušek, CSc.

# Prohlášení

Prohlašuji, že bakalářskou práci na téma *Medical Robotics* jsem vypracoval samostatně pod vedením vedoucí bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne .................................... ........................................

Michal Herman

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# 1 Introduction

Although medical robots have developed tremendously over the past few decades and their influence on improving overall patient care is undeniable, it is still considered the beginning of their development. Given that robotics and healthcare are fields that complement each other very well, it is clear that both sectors will develop further. The field of medical robotics is much broader than people usually think. In most cases, it is believed that robotics is only for surgeons, dentists, ophthalmologists and usually used only in hospitals, but the opposite is true. Robotics also serves people who are in any way old or disabled, or dependent on others and who could not live a normal life. It is also used for X-rays, socialization, rehabilitation and interaction with people, not only in hospitals but also in homes.

Regarding surgical operations, some of them would not even be possible today if medical robots were not available and so well-developed. Today, operations are performed with such accuracy, quality, dexterity and safety that it leads to faster patient recovery, shorter hospital stay, reduced blood loss, minimal scarring, reduced risk of infection and lower overall costs. Medical robots also enable patients to communicate with doctors and specialists who, through robot assistance, can carry out medical examinations at home.

The aim of this bachelor's thesis is to list and describe robots used in medicine. The first chapter will deal with a history of robots, their gradual development, and it will describe the first robot used for surgeries called Puma 560. The second chapter will explain implementation of medical robots into medicine and advantages they have over people. The third chapter will focus on the future of medical robotics. Besides, it will discuss robots that are being tested in medicine. The last chapter will deal with assistance robots that help the elderly in their daily lives.

# 2 Survey of Medical Robots from the Historical Point of View

The word “robot“ derived from word “robota” (forced labour) was first used in a science-catastrophic drama *R.U.R. (Rossom’s Universal Robots)* written by the novelist Karel Čapek. This word was not actually Karel Čapek’s idea, but it was recommended to him by his brother Josef Čapek.

As Husty and Hofbaur (2018, p. 160) note, “The term ‘robotics’ was introduced by Isaac Asimov in 1938 in his short story *Runaround* published in the magazine *Super Science Stories*, followed in 1942 by publishing of a collection of short stories *I Robot* in which robots coming into conflict with their owners are described.” Isaac Asimov is also the first person to state 3 Laws of Robotics:

1) “A robot may not injure a human being, or, through inaction, allow one to come to harm.”
2) “A robot must obey all orders given to it from humans, except where such orders would contradict the First Law.”
3) “A robot must protect its own existence, except when to do so would contradict the First Law or the Second Law.”

Considering robots, these 3 Laws of Robotics are still recognized and respected up to the present day.

With the beginning of the second half of the 20th century, the robot described by Karel Čapek and Isaac Asimov has slowly started to take its place in factories and medicine. Shortly after their implementation in medicine, robots were considered as something that would broaden the capabilities of the human, increase productivity and minimize errors. The very first robot used in surgery was called Puma 560. Dr. Yik San Kwoh of the Long Beach Memorial Medical Center used this robotic arm to direct a needle into his patients’ brain on 11 April 1985 (Gomes, 2012).

## 2.1 First Surgical Robot – Puma 560

According to Bond Simulation (2019), the very first robot used in surgery, released in 1978, is called Puma (Programmable Universal Machine for Assembly) 560 (see Figure 1). As Bond Simulation (2019) points out, this robotic system originally derived from the industrial type of robots and was developed by Victor Scheinman at Unimation[1]. The robotic system was first used at Memorial Medical Center, Long Beach in USA California in year 1985. This robot eliminated the hand tremors, and thus allowed the surgeon to perform more complex procedures such as neurosurgical biopsy[2] of brain explained by David and Samadi (2019). Puma 560 was able to work with accuracy of 0.05 mm. Three years later it was used for performing more complex procedure called transurethral resection[3] for the first time. Puma robot was operated by controllers called Unival, Mark1, Mark2, Mark3 and program languages used are called VAL 1 and VAL 2 as explained by Jokic, Lubura, Stankovski (2014, p. 2).

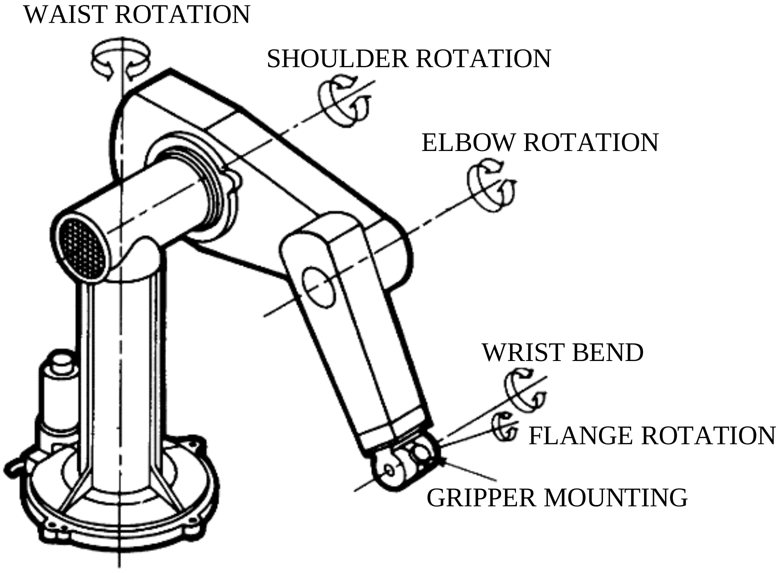

*Figure 1*. Puma 560.
Adapted from https://www.researchgate.net/figure/Schematic-structure-of-PUMA-560-robot-arm_fig1_265601856

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[1] Unimation was the world's first robotics company founded in Danbury, Connecticut, in 1962 by Joseph F. Engelberger and George Devol (Port, 1997, March 3).

[2] Biospy is the removal for diagnostic study of a piece of tissue from a living body (*dictionary.com*, n.d.).

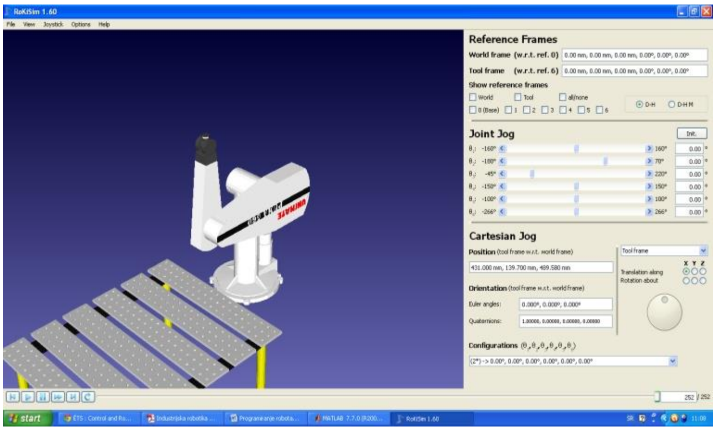
[3] Resection is a surgery used to treat urinary problems that are caused by an enlarged prostate (Mayo Clinic, 2019).

### 2.1.1 Programming

Jokic et al. (2014) further explain that, at a time when Puma 560 was designed, two programs called RoKiSim and Matlab were used for programming its movement:

> Namely, program package RoKiSim can be used for the purposes of obtaining values of joint angles by bringing robot’s top to desired positions in the simulator whereas program package Matlab can be used for the purposes of generating trajectory between two positions defined by joint angles” (p. 2).

Since there was no single program that suited programming of Puma 560, it was decided that combination of both programs would be used to achieve the desired result. Figure 2 illustrates RoKiSim, a program mainly used for graphical demonstration of a robot. On the other hand, Matlab (see Figure 3) is used for computing a large amount of data. Curves of the individual positions obtained were then connected and whole trajectory could again be tracked by RoKiSim.



World frame (w.r.t. ref. 0) 0.00 mm, 0.00 mm, 0.00 mm, 0.00°, 0.00°, 0.00°

Tool frame (w.r.t. ref. 6) 0.00 mm, 0.00 mm, 0.00 mm, 0.00°, 0.00°, 0.00°

$\theta_1$: -160° 160° 0.00 °

$\theta_2$: -180° 70° 0.00 °

$\theta_3$: -45° 220° 0.00 °

$\theta_4$: -150° 150° 0.00 °

$\theta_5$: -100° 100° 0.00 °

$\theta_6$: -266° 266° 0.00 °

Position (tool frame w.r.t. world frame) 431.000 mm, 139.700 mm, 489.580 mm

Tool frame

Translation along ● X ○ Y ○ Z

Rotation about ○ X ○ Y ○ Z

Orientation (tool frame w.r.t. world frame)

Euler angles: 0.000°, 0.000°, 0.000°

Quaternions: 1.00000, 0.00000, 0.00000, 0.00000

Configurations ($\theta_1$,$\theta_2$,$\theta_3$,$\theta_4$,$\theta_5$,$\theta_6$)

(2*) -> 0.00°, 0.00°, 0.00°, 0.00°, 0.00°, 0.00°

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*Figure 2*. RoKiSim. Reprinted from Jokic et al. (2014, p. 1).

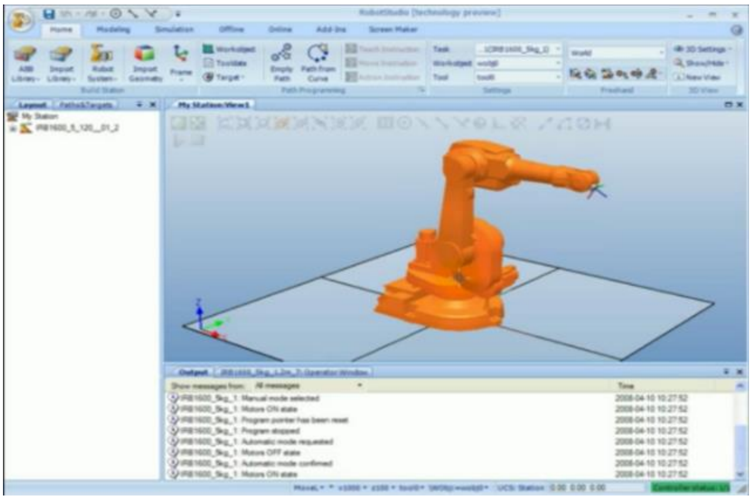

*Figure 3*. Matlab. Reprinted from Jokic et al. (2014, p. 1).

# 3 Contemporary Medical Robots

Husty and Hofbaur (2018 p. 161) explain that after robots were introduced in the second half of 20th century, the use of robots has developed tremendously, since "they are used in a variety of applications, including space exploration, military field, medicine, etc.". Robots have been developed mainly because of several advantages over a human such as accuracy, fewer errors and ability to repeat a single movement repeatedly without getting tired. Nowadays we have two types of medical robots. The first type of robots is mainly based on industrial robots. Those robots enable the fulfilment of a lower or higher degree tasks. The second type of robots is designed to aid surgeons in operating. This type of robots is therefore not capable of its own movement, but instead it is used to replicate the surgeons' movement or assist them in any way.

## 3.1 da Vinci Surgical System

As Watanabe (2014, p. 9) explains, "the da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA) is at present the most commonly used robotic system for performing minimally invasive laparoscopic surgery in humans". It is designed to expand the surgeon's capabilities and enable them to perform complex surgical procedures. The da Vinci was named after Leonardo da Vinci[4] who invented the first humanoid robot. It was made by an American company called Intuitive Surgical in 1999. This company has its own partners that distribute their product to the Czech Republic, Slovakia, Slovenia, Russia, Hungary and to other countries of Europe. Nine of these robots are used in the Czech Republic, for instance in the military hospital in Prague and in the university hospitals in Brno and Olomouc.

Tsuda and Kudsi (2018, p. 7) explain, that "the da Vinci System is based on three distinct subsystems" as illustrated in Figure 4. The first subsystem is an ergonomically designed surgical console. The second subsystem is called Vision Cart and the last is a Patient cart equipped with four robotic arms. As you can see in Figure 4, the multi-armed system is controlled by the surgeon, thus enabling to perform surgeries which were not possible before.

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[4] Leonardo's robot or Leonardo's mechanical knight was invented around 1495. The robot could stand, sit, raise its visor and independently manoeuvre its arms, and had an anatomically correct jaw. The entire robotic system was operated by a series of pulleys and cables (Rosheim, 2006).

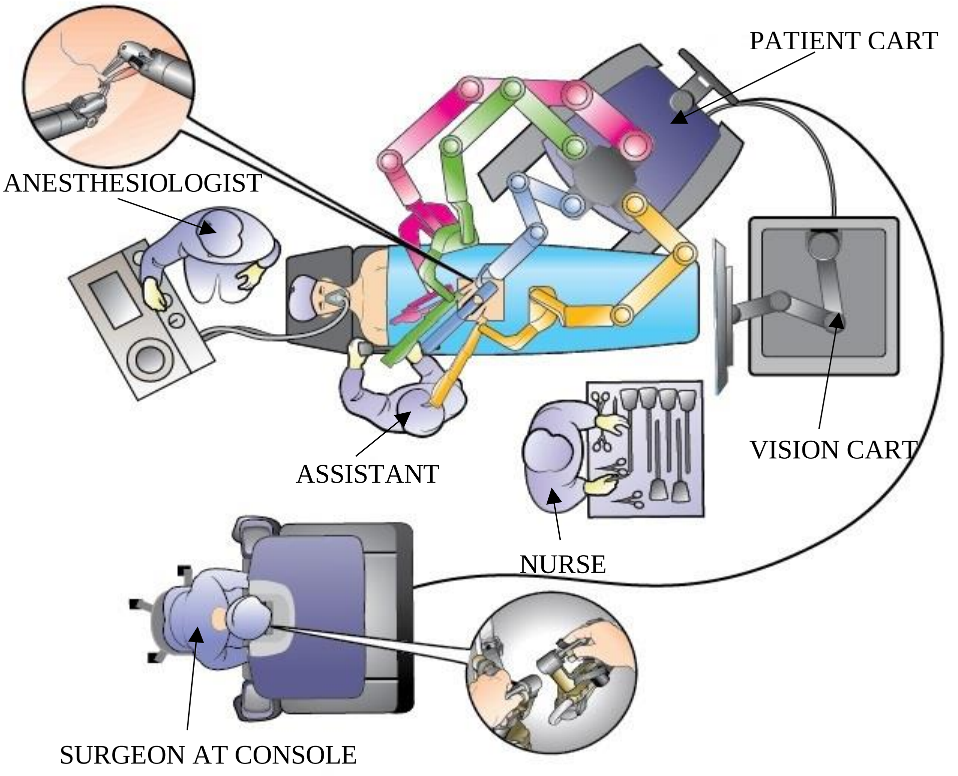

*Figure 4.* Surgical System da Vinci.
Adapted from https://blog.sciencemuseum.org.uk/robot-surgery-the-da-vinci-robot/

### 3.1.1 Surgical Console

*Figure 5*. Surgical console.
Reprinted from https://www.intuitive.com/en-us/products-and-services/da-vinci/systems

The surgical console, illustrated in Figure 5, is considered as the core of the da Vinci system since it is a place from which operations are being carried out. As Mishra (2019, p. 41) describes, "the surgeon console operator sits outside of the sterile field and controls instruments and a 3D endoscope with his/her hands, using two master controllers and with his/her feet, using foot pedals. It is also considered the control unit for the rest of the parts". While operating, the surgeon is provided with excellent light technology and a stereoscopic monitor that enables them to a see real-time high definition 3D view of the surgical site. System settings, audio and video can be changed via stereoscopic monitor as well. Besides, the surgeon can switch between different types of views from the 3D view to the multi imaged and full screen view. The surgeon can also switch between energy sources, which are controlled through a footswitch on the bottom side of the console. Surgery is possible to be carried out from distance up to 10 m from the operating table (Husty & Hofbaur, 2018).

According to Husty and Hofbaur (2018, p. 163), "da Vinci transmits movements of the surgeon hands, wrists and fingers to the instruments in the surgical field, in real time, with tremor filtration". The da Vinci system also controls each movement of the surgeon in order to prevent any rapid or fast movements. In such a case, the da Vinci automatically stops, and the last step must be repeated, but this time not as fast and rapidly. When an eye contact with the screen is interrupted, the robot automatically stops at that position.

### 3.1.2 Vision Cart

The vision cart is a part of the da Vinci system that consists of image processing equipment (see Figure 6). The vision cart can be operated via a touch screen, or manually. The cart of the da Vinci can be easily manoeuvred around the operating theatre thanks to its wheeled base. The robotic cart is connected to the console and to the tower which processes records through the colour coded cables or digitally. The vision cart is managed during surgery mostly by a non-sterile assistant. Nowadays, there are two types of a vision system. An SD vision system which stands for Standard Definition, and an HD vision system which stands for High Definition (Mishra, 2019).

*Figure 6*. Vision cart.
Reprinted from https://www.intuitive.com/en-us/products-and-services/da-vinci/systems

### 3.1.3 Patient Cart

According to Tsuda and Kudsi (2018, p. 8), “the patient-side cart is positioned adjacent to the patient during the operation.” The da Vinci patient cart is equipped with four arms called working arms and a displaying arm (see Figure 7). More specifically, the three arms are used to hold surgical instruments and the fourth arm holds a camera. Each arm has a very high level of manoeuvrability (similar to human) because of its endoscopic[5] wrist. Moreover, each arm is covered in sterile drapes, consisting of adapters (used for mounting of a camera and other necessary instruments), which are sterile as well. The camera and tools replacement are executed by a specialist called the bedside assistant. The instruments mounted to da Vinci patient cart can be changed according to need of the surgeon. When operating, its equipment is inserted into the patient through small injections, and consequently it mimics the surgeon’s hand movements. Every single movement is controlled by a computer which makes sure that every single movement is precise. The other significant features of the da Vinci system are detailed visualization, possible configuration and elimination of shakiness which used to happen when surgery lasted too long (Tsuda and Kudsi, 2018).

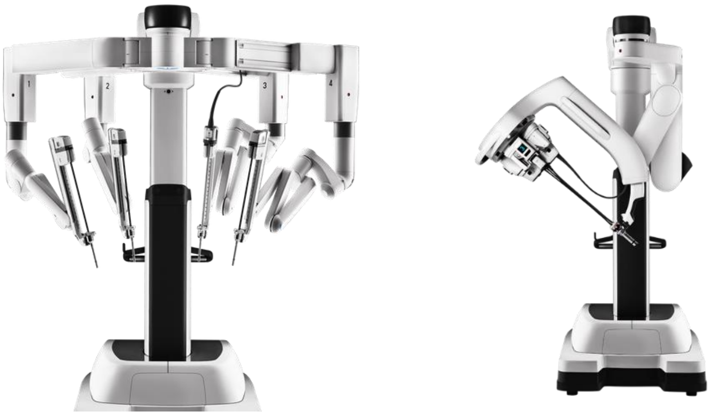

*Figure 7*. Patient Cart.
Reprinted from https://www.intuitive.com/en-us/products-and-services/da-vinci/systems

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[5] Endoscopis is a slender, optical instrument used as a viewing system for examining an inner part of the body and, with an attached instrument, for biopsy or surgery (*dictionary.com*, n.d.).

### 3.1.4 System Setup and Operating Theatres Configuration

Gao (2013) explains that since the surgical system da Vinci consists of three main components (the Surgical Console, the Patient Cart and the Vision Cart) and cables, it is necessary to arrange them carefully to achieve maximum safety and efficiency when operating. The Surgical Console (positioned outside sterile field) should be placed and turned so that the surgeon can observe the whole operating theatre and communicate with the operator of the patient cart. Before surgery, the patient cart as well as the arms of a da Vinci are covered by sterile coat to prevent contact with any non-sterile object. Connection of individual components of a da Vinci is done by three main cables (distinguished by colour) which should be arranged in such way that they do not interfere with the operation, do not bind surgeons, operators and are not in a way of other equipment. Another very important aspect of smooth operation without any complication is preoperative management. Two nurses called a scrub nurse[6] and a circulating nurse[7] are usually assigned to scrub and take care of non-sterile components.

## 3.2 Xenex Germ-Zapping Robot

Cleanliness of operating theatres plays a major role in protecting patients, family members and employees from infections such as pathogens[8], viruses, mould, microorganisms and other resistant organisms according to Miley (2017). The Xenex is a LightStrike robot (see Figure 8) which kills all kinds of viruses by emitting ultraviolet light. Even though ultraviolet light has been discovered more than two hundred years ago by Johann Ritter, it is just now being

*Figure 8.* Xenex Germ-Zapping robot. Reprinted from https://jrmcnd.com/public-asked-to-name-the-robot/xenex-lightstrike-robot/

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[6] A scrub nurse is a nurse specially trained to assist surgeons in the operating room and serving as part of the surgically clean medical team handling instruments during an operation. (*dictionary.com*, n.d.)

[7] Circulating nurse is a registered nurse who makes preparations for an operation and continually monitors the patient and staff during its course, who works in the operating room outside the sterile field in which the operation takes place, and who records the progress of the operation, accounts for the instruments, and handles specimens (*merriam-webster.com*, n.d.).

[8] A pathogen is an agent, such as viruses, bacteria, fungi, protozoa, and worms, that causes a wide diversity of diseases (*Encyclopedia.com,* n.d.).

implemented into the medical field as a safe method of cleaning and disinfecting operating theatres as well as bathrooms, equipment rooms, emergency rooms and other places commonly used by patients and hospital employees. Miley (2017) further explains that ultraviolet light emitted by Xenex eliminates bacteria by penetrating their cell walls which leaves them unable to further reproduce themselves or mutate. The Xenex is used in hospitals as an additional cleaning tool, which is used after the rooms were cleaned by cleaning teams. As the cleaning teams are in most of the cases unable to kill all the bacteria and viruses resistant to antibiotics, the Xenex helps them with their elimination, which usually lasts between 4–10 minutes states Hart (2016). Electronics Council (2019) adds that with such speed, the Xenex can clean up to 60 rooms a day, so there is no need of having multiple robots in one hospital. Another advantage is its portability and silence, which leads to undisturbed operations. The germ-zapping robot is usually placed close to places of highest concentration of people. The elimination of the infections is said to be reduced by 70 %. The latest version of the Xenex robot is also equipped with both wi-fi and cellular connectivity, which enables hospital staff to see real-time data and consequently make elimination of viruses more efficient. Another feature, perhaps the most interesting one, is the added security measure. Since UV-C[9] emitted by Xenex could be harmful to humans (only if humans were exposed to ultraviolet light for too long), Xenex is equipped with sensors which ensure that people are not nearby or warn people when being too close or entering the room.

Compared to its predecessors, the latest edition of Xenex is much smarter and easier to use due to the implementation of high-quality parts. One disinfection cycle used to take up to forty-five minutes, which resulted in overheating of the device. The overheating was mainly caused by mercury lamps, which also had a negative impact on people. For this reason, the robot needed to be cooled down during the work and people had to keep away from it.

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[9] UV-C stands for short-wavelength ultraviolet light that covers a wavelength spectrum from 200 to 280 nm and has the strongest germicidal effect (Howard et al., 2008).

## 3.3 Telepresence Robot

According to Telepresence Robots (2016), telepresence is a set of technologies which enable users to appear in a remote location in real time. Figure 5 shows a telepresence robot that represents a perfect device for medicine when it comes to non-life-threatening situations. The main purpose of this project is to save surgeons' and specialists' time and enable them to examine patients' health status and identify possible illnesses without physically commuting to their homes. This robot consists of two main parts: the robot itself, which performs the instructions given by the surgeon, and the workstation, which is a place from which the robot is managed. Both parts are connected to the wireless network to be able to communicate with each other over long distances.

### 3.3.1 Components of Telepresence Robot and the Workstation

The key components of the telepresence robot are a camera (which enables visual contact between the surgeon and patient), an LCD screen (which displays required information), a microphone (to communicate with the patient) and speakers . The telepresence robot further provides a receipt printer, a scanner (used to scan documents, send images and prescriptions), sensors (to dodge potential obstacles) and wheels (see Figure 9) (Bugtai et al., 2017).

*Figure 9*. Telepresence robot.
Reprinted from https://aip.scitation.org/doi/pdf/10.1063/1.4976787

Bugtai et al. (2017, p. 3) point out that “the workstation has a dimension of 590 mm x 382 mm x 360 mm and is enclosed in a galvanized iron sheet with wheels to support mobility” (see Figure 10). The other components which are parts of the workstation are Tactical II system (a screen used for communication with the patient), a control screen (used for display of the patient database), a camera (a communication device), a microphone, speakers, a remote control (used for changing information displayed on the LCD) and other supplementary devices such as a mouse or a keyboard (Bugtai, 2017).

*Figure 10*. Workstation.
Reprinted from https://aip.scitation.org/doi/pdf/10.1063/1.4976787

### 3.3.2 Programming

Applications used in the robot are Java[10] and PHP[11] and are installed in the computer unit of the robot. These programs can be accessed only by the surgeon and enable communication between the surgeon or specialist and patients. Communication is possible because of Java which establishes a server-client connection similar to a telephone call. Initial instructions for the robot’s movement are sent through Java which immediately returns required information concerning the battery and sensors to the workstation. “The PHP application is further used for the Patient Database, enabling the doctor to create and update patient information and receive data such as scanned images” (Bugtai et al., 2017, p. 4).

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[10] Java is a high-level, object-oriented programming language used primarily to build web-based applications (*dictionary.com,* n.d.).

[11] PHP is a scripting language used primarily for web development (*dictionary.com,* n.d.).

## 3.4 Yomi Dental Robotic System

Srivastava et al. (2019, p. 63) report that „approximately 3 million individuals get 5.5 million implants every year in the United States; this number is developing by an extra 500,000 additional patients each year.“ This recent increase in demand for dental implants and its expected increase in the future have resulted in the development of a robot called Yomi. The insertion of implants is a very demanding procedure in which it is necessary to place the implant exactly in a predetermined place. Even minor complications can result in unevenness in the placement of the prosthesis. The great advantage of dental implants is that there is no need to shrink the adjacent (contiguous) teeth of the implanted tooth. Teeth shrinkage often resulted in tooth decay, which required further intervention.

Together with testing and development of the Yomi robot, experts have created a new computer-controlled system for oral implantology. Based on CT scans taken before the procedure, the task of this system is to "render an objective district and a pathway associated with relative organs from figured CT information" (Srivastava et al., 2019, p. 63). It further provides a position and trajectory of a surgical instrument in real time and 3D.

### 3.4.1 What Is the Yomi Robot

The Yomi robot is the first robot developed exclusively for oral implantology. Developed by Neocis, this robot represents a breakthrough in dentistry. Yomi utilizes Haptic guidance and multisensory feedback to accurately place the implant. The implant is placed using a robotic arm (see Figure 11) controlled by a specialist. This robotic arm enables specialists to acquire correct angulation and profundity during the procedure.

The procedure is led by the Yomi robot during which it is constantly observed and monitored by a specialist. As the Yomi robot does not contain any cameras and physical assistants, it allows the specialist better control over the device and the procedure itself. During the procedure, Yomi evaluates the changes that may occur, which again allows the specialist to have control over the procedure (Srivastava et al., 2019). If we take into account all the advantages of the Yomi robot, it can lead to faster surgical procedure, faster patient recovery and less pain.

Figure 11. Yomi Robotic Implant Surgery System.
Reprinted from https://dentistrytoday.com/products/product-highlights/item/4297-materials-get-fda-clearance-for-robotic-implant-surgery-system

### 3.4.2 Haptic Guidance

According to Mugge (2016), systematic as well as random errors are made by people when doing learned movements. Haptic guidance therefore helps with reduction of such mistakes. Srivastava et al. (2019, p. 64) define haptic guidance as "the ability for a robotic system to physically guide a surgeon so they can perform surgery exactly as the planned preoperatively, relative to the patient's CT scan". Haptic guidance of Yomi guides the surgeon to predetermined position, therefore any mistakes are eliminated. When the robotic hand reaches the desired location, the surgeon can further perform implant placement.

### 3.4.3 How Does Yomi Work

The procedure described by Srivastava et al. (2019) starts with the CT scan of the patient's head. The following step involves Yomi's software evaluating the captured images and designing the procedure suitable for the patient. For an accurate plan of the procedure, Yomi software uses the dimension of a human face and head. The next step involves the haptic guidance, where the hand of the surgeon is guided to the place, where intervention will be carried out. During the procedure, the surgeon is in the charge in case of any changes or adaptation should be made.

## 3.5 CyberKnife

Even though this robot is called the CyberKnife, no knife or cutting is involved in any of the procedures. This type of a robot is rather used to treat both types of tumours (cancerous and non-cancerous) non-invasively (CyberKnife Accuray®, 2013). The idea for this robot arose in the 1950s when a Swedish professor Lars Leksell came up with term stereotactic surgery: “A neuro-surgical procedure that combined precision targeting with a large number of cross-fired beams of ionizing radiation” (Srivastava et al., 2015, p. 106). A predecessor of CyberKnife was Gamma knife, which according to Naff (2007) was the first robot to precisely distribute beams of radiation on the treated part of the human body. In the 1990s, the John Adler’s design, which closely resembled today’s CyberKnife, was tested. At that time, the robot already had a robotic arm with 6 degrees of freedom (Kurup, 2010). Figure 12 shows that the CyberKnife is composed of two main parts. The first part is a device delivering radiation and is called linear accelerator, or Linac. The second part of ~~a~~ the CyberKnife is a robotic arm which enables unrestricted (non-isocentric) movement of the whole system around the human body. To provide the highest accuracy of treatments possible, the system is equipped with advanced imaging software which scans the human body during the procedure and evaluates in which direction radiation beams should irradiate. Kurup (2010) explains that the CyberKnife is compared to other very precise radiosurgery systems: “Unlike other linac-based systems, which have accuracy in millimetres, the CyberKnife has sub-millimetre accuracy in tracking tumour position. If sub-millimetre accuracy is not achieved, it gives warning and stops treatment” (pp. 63–64). Due to its self-adjusting and very precise system patients are not forced to lie still during the procedure (CyberKnife Accuray®, 2013).

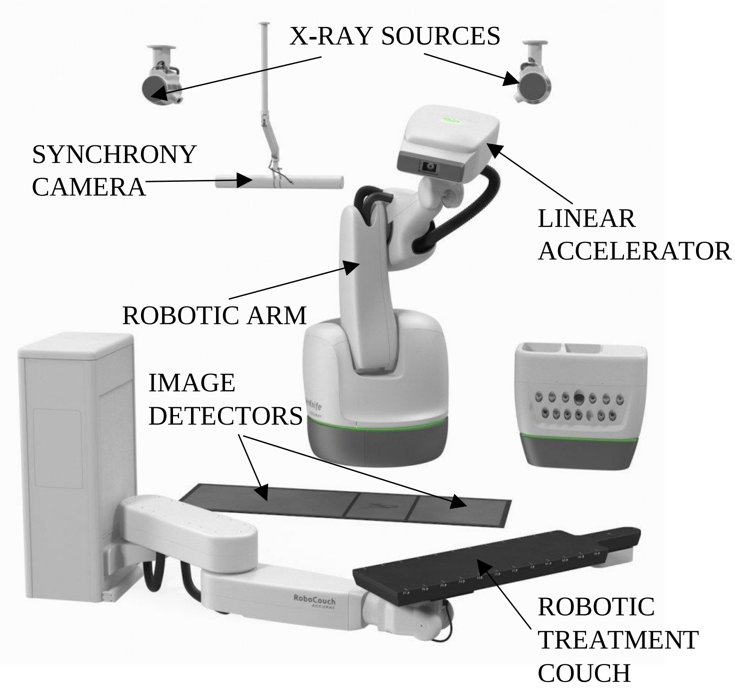

*Figure 12*. CyberKnife. Adapted from https://qmro.qmul.ac.uk/xmlui/bitstream/handle/123456789/8390/A%20Martin_MD%28Res%29.pdf?sequence=1&isAllowed=y

Compared to radiation therapy, which in average takes two to four weeks the CyberKnife system is much faster. Treatment usually lasts one up to five days, does not involve any surgical intervention and is pain-free. Individual treatments are then adjusted according to the type of tumours. Before application in practice, learning and training of the system by radiation oncologists, technicians and medical physicists is necessary. Hospital staff should also understand the biology behind treatment since many different methods and procedures are available for different types of tumours (CyberKnife Accuray®, 2013).

### 3.5.1 Robotic Arm

An arm carrying a linear accelerator, as illustrated in Figure 13, is called Kuka KR 240-2 (Series 2000), which was made in Augsberg, Germany. This robotic arm enables the linear accelerator to freely move around the human body in any 3-dimensional angle, which is possible due to six embedded joints (Martin, 2012). According to Kuka (2002), its maximum payload differs according to rating classes. There are five of them that range from 150 to 270 Kg payload and 2700–3000 mm of reach. Kuka robotic arm offers a wide range of possibilities and options of customization for optimal application. This type of a robot is used not only for medical application, but also for many different industries, therefore Series 2000 offers different variants: Foundry (F) used in environments with extreme temperatures and high degree of pollution, Cleanroom (CR) mostly used in medical industry and an alternative type with H1 food-compatible oil.

*Figure 13*. Kuka KR 240-2 (Series 2000).
Reprinted from: https://sealing-system.dk/en/packaging-solutions/kuka-kr-120-pa/

### 3.5.2 Robotic Treatment Couch (RoboCouch)

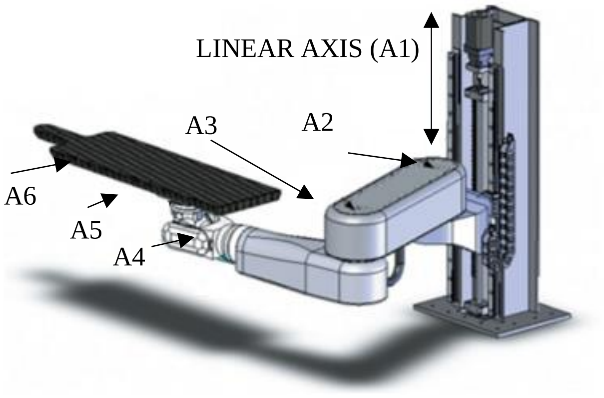

*Figure 14.* Robotic treatment couch.
Adapted from
http://www.cyberknifelatin.com/pdf/brochure-tecnico.pdf

According to CyberKnife Accuray® (2009), the robotic couch disposes of 6 degrees of freedom mechanism (A1-A6) for accurate positioning of the patient (see Figure 14). Martin (2012) observes that the treatment couch is mounted on another Kuka robotic arm that is part of the CyberKnife system and CyberKnife Accuray® (2009) states all possible positions of the treatment couch: “the 3 translational (left-right, superior inferior, anterior-posterior) and 3 rotational (roll, pitch, yaw) planes.” The CyberKnife system as a whole is very dependent on the high level of manouverability, which is vital for the patient’s correct position and the subsequent delivery of dose; therefore, both the robotic arm and the robotic treatment couch have many options of settings of positions.

### 3.5.3 Synchrony Camera

Ozhasoglu et al. (2008) explain that human organs can move approximately 40 mm due to the respiratory motion. This motion needs to be compensated during the therapy because the dose of external beam might not point to the required place and can eventually threaten patient’s health. For that reason, an external synchrony camera was added to the CyberKnife system for dynamic targeting of tumours that move. The synchrony camera is continually updating the motion of the tumour during the procedure, which makes it possible for the system to sequentially adjust the motion without any human intervention. With introduction of the synchrony camera the precision became much more accurate (up to 1 mm). Tracking is done using external markers linked to X-ray images enabling the robotic arm to stay aligned with the target. As a result, patients can lay comfortably and breathe freely.

### 3.5.4 Types of Tracking

6D Skull Tracking is “the method of tracking for all intracranial lesions and some head and neck tumours which are felt not to move relative to the skull” (Martin, 2012, p. 41). The skull has a lot of bones. 6D software therefore analyses images gathered both during setup and treatment with DDRs and, eventually, with the help of rigid transformation the tracking system can be adjusted in 6 different directions of movement. System accuracy ranges between 0.44 – 0.48 mm. To assure the accuracy, the patient is clothed with a thermoplastic shell, which prevents extensive head movements of patient (Martin, 2012).

In Xsight Spine Tracking, the difference between the skull and the spine is its independent movement of vertebrae. Rigid transformation is thus not genuine between live images and the DDR. Martin (2012, p. 4) notes that “instead the software performs non-rigid image registration based on a bony region of interest near the target.” Like 6D skull tracking, its accuracy ranges between 0.52 – 0.61 mm. Most of the tumours which are located within a few centimetres of the spinal column can be therefore treated (Martin, 2012).

## 3.6 Gamma Knife

Gamma Knife is very similar to CyberKnife in the way it operates, and for which purpose it is used for. Nevertheless, gamma knife is used specifically for treatment of tumours (usually very small) located inside the brain (see Figure 15). Furthermore, it is used for treatment of blood vessel malformations[12] and is tested for possible future treatment of diseases such as Epilepsy or Parkinson. According to Radiology (2019), treatment delivered to the target area does not affect surrounding tissue, which is very important. Niranjan et al. (2014) explain that gamma knife was first used in year 1967 under direction of Lars Leksell in Stockholm, Sweden. Since then many changes have been implemented. One of the first models were U and A, but due to reloading issues they were rebuilt into the models B, C and 4C. Nowadays, different types of beam diameters are used according to shape, size and location of the target.

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[12] Malformation is an abnormal tangle of blood vessels connecting arteries and veins, which disrupts normal blood flow and oxygen circulation (Mayo Clinic, 2019).

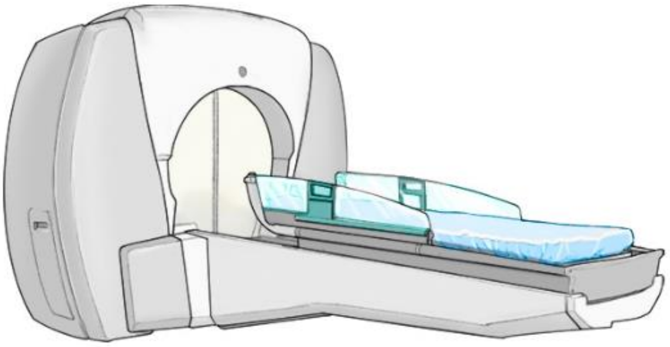

*Figure 15*. Robotic treatment couch.
Reprinted from https://webflow.com/website/daniel-suhs-dandy-site

Before a procedure starts, the doctor, or a qualified member of the Gamma Knife team explains the individual steps of the procedure to the patient and informs them about the possible scenarios and risks associated with it. If ~~you~~ they are familiar with the procedure and have no further questions, they have to sign a consent form before undergoing the procedure (NYU Langone, n.d.). The procedure starts with the neurosurgeon attaching a light-weight aluminium stereotactic frame (acting as a guiding device) onto the head of the patient (see Figure 16) who is under local anaesthesia (Niranjan et al., 2014). Four pins are used to firmly attach the frame onto the patient's head. For correct positioning and balancing of the pins, the plastic ear bars are placed onto each ear. The head frame ensures that the patient's head remains in the identical position because treatment depends heavily on accuracy of captured images. Depending on the examination and diagnosis of the patient, MRI, angiogram, or CT scan is underwent, providing the Gamma Knife team with necessary results (shape, size, location, etc.) of tumour (NYU Langone, n.d.). The following step includes a personalized treatment plan which is prepared individually for each patient by the Gamma Knife team (Radiology, 2019). NYU Langone (n.d., p. 6) describes that after completing the plan, "you will be transported into the Gamma Knife treatment room. You will be moved onto the couch and your head frame attached comfortably to the table. You will then enter the domed section of the unit, where your treatment will begin". The Gamma Knife system then analyses if the position of the patient is correct. Once everything is in perfect order, the system delivers a predefined amount of radiation accurately on the afflicted place. The treatment lasts from 15 minutes up to 3 hours and depends on the number of treated sites and the size of tumours. After the procedure is finished and all the steps are completed, the aluminium head frame is removed and spots where the pins pressure was applied are covered with gauze. Since the pressure applied onto the head of the patient is relatively high during the procedure, it can start bleeding, therefore a small stitch can be used to stop it. As mentioned earlier, the length of the procedure can last up to 3 hours, which can result in swelling, thus medication called Decadron is prescribed. The patients who underwent the procedure are in most cases sent home after a few hours; in some cases, they are kept in hospital overnight. Before the patients are sent home, they are acquainted with activities they can do during convalescence and are acquainted with dosing of tablets and care taking of pin-damaged areas (NYU Langone, n.d.).

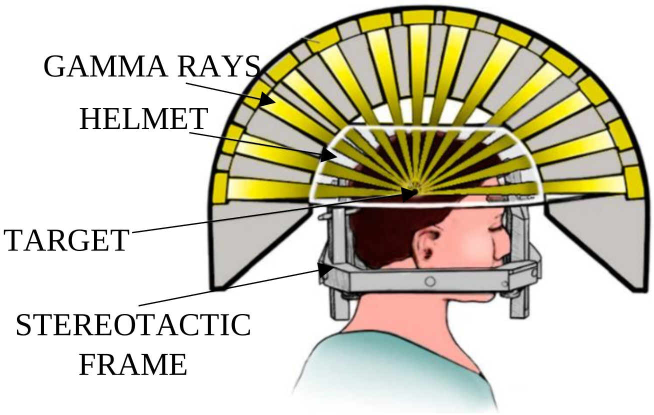

*Figure 16*. Gamma Knife delivery of radiation.
Adapted from https://www.mayoclinic.org/tests-procedures/brain-stereotactic-radiosurgery/about/pac-20384679

# 4 Future Development of Medical Robots

When it comes to the future of medical robots, we can divide them into two groups. The first group would be the robots that are still considered as a vision today and most likely will not be a part of surgical therapeutics within another decade. Such robots are seen as robots which, for example would be capable of being swallowed or injected into the bloodstream and make a targeted therapy, or robots which would be able to operate on their own without human assistance (Husty and Hofbaur 2018). The other group of robots are those that have not been implemented into surgical therapeutics, for example a robot called HeartLander, or Sophia which is a robot based on artificial intelligence. But as Husty and Hofbaur (2018, p. 164) explain, “mini-robots, like HeartLander are in the process of development and in the next decade will likely be part of a surgical therapeutics”.

## 4.1 HeartLander

The mini-robot called HeartLander has been developed by Carnegie Mellon University and according to Chapman et al. (2010) its job is to carry out minimally invasive[13] surgeries which significantly improve a recovery of patients and decrease the risk that an open surgery involves. Moreover, HeartLander can map, treat and sense the entire surface of the heart and therefore provide surgeons with valuable information according to the Robotics Institute (2019). According to Gomes (2012), HeartLander is inserted through small incisions and attached to the heart using a suction system, and it can easily maneuver around due to its flexible push (drive) wires (see Figure 17). Plastic sheets are connected to the rear body and, as Patronik et al. (2009) state, they cover push (drive) wires. Gomes (2012) further explains that HeartLander is firmly attached to the surface of the heart and thus not disturbed by the heartbeat. According to Jobbágy (2012, p. 227), “the crawler has been tested in vivo many times in a porcine model, a model which provides generally authentic conditions in many ways.”. Even though the porcine hearts does not have the same amount of epicardial[14] fat as human hearts, tests are still carried out to see how the robot manoeuvres around. The developers’ main concern is to find out how epicardial fat will affect the robots suction

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[13] Minimally invasive - requiring only a small incision or the insertion of an instrument into a body (*dictionary.com*, n.d.).

[14] Epicardial is term used by some cardiac surgeons meaning “on the outside of the cardiac muscle (heart muscle)” (definitions.net, n.d.).

system because each person has a different amount of epicardial fat and the suction system could get clogged up. For that reason, ovine hearts were used instead to imitate the human heart. In case of an average amount of epicardial fat, the suction system did not get clogged up, even though there was some fat accumulated in the suction chamber. HeartLander could still generate traction and maneuver around. The suction system did not work accordingly just in case of exposed fat, which affected the suction system pad. For this reason, the developers do not expect HeartLander to ever work in such conditions.

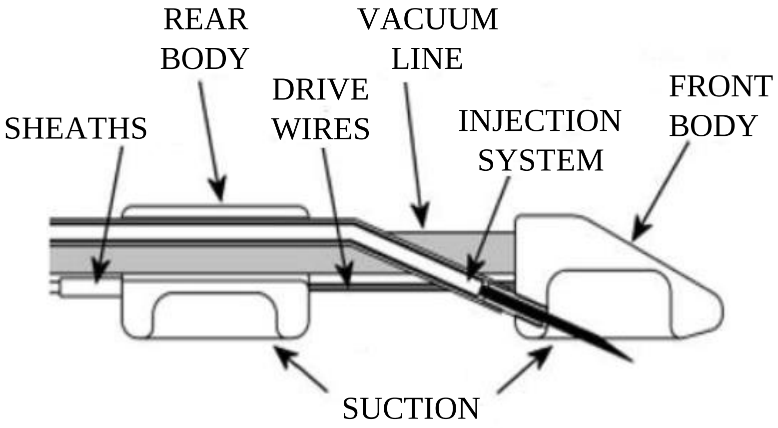

*Figure 17*. HeartLander.
Adapted from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2826133/

### 4.1.1 Locomotion

According to the Robotics Institute (2019), locomotion is a movement which results in progression from one place to another. The coordinates and timing of the robot are controlled by the computer, which is managed by the surgeon and the motion is controlled by electronic valves and pressure sensors. As shown in Figure 18, the black spot represents the part of the robot called “rear suction” which is active in the first step and, therefore, enables the white parts of the robot called “front suction” to move in the required direction. When the front suction reaches its required destination, the computer recognizes it and the suction is switched from rear to front. This movement is performed until the robot reaches the desired destination.

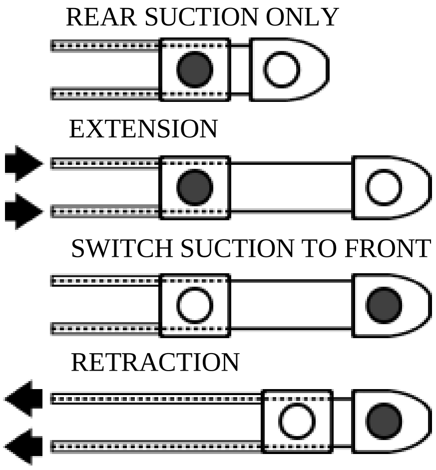

*Figure 18.* Locomotion of HeartLander.
Reprinted from: https://www.cs.cmu.edu/~heartlander/design.html

## 4.2 Sophia – the Robot with a Human Face

Humanoids, as they are sometimes called, are robots with a human face. One of the examples is Sophia, which is a social and most advanced prototype of the humanoid robot based on artificial intelligence. Sophia was developed by the Hong Kong company Hanson Robotics and was activated on 19th April 2015 (Retto 2017). This robot has a look of with middle-aged woman. According to Retto (2017, p. 4), “the British actress Audrey Hepburn has served as a model to design the face of Sophia, who still lacks lower extremities, which are in the process of being built”. Its future essence lies in interaction with people, service, entertainment and it is considered to be the future of artificial intelligence and robotics. As an artificial intelligence robot, Sophia is expected to learn from experience, accumulate knowledge, express emotions, learn from its own mistakes and learn human behaviour. Nevertheless, Sophia is still in its testing phase as the artificial intelligence researchers try to understand her potential to the fullest. Continued improvements in Sophia’s development suggest that it can be used in medicine within the next few years. As Hansons Robotics (2019) notes, Sophia attended TV shows such as *Tonight Show* and *Good Morning Britain* and took part in hundreds of conferences all around the world. Lately, there have been some speculations regarding Sophia’s look, as some people think that it looks too scary to be a part of the healthcare industry, but some people think the exact opposite.

Retto (2017, p. 6) further explains that “her eyes are cameras with the ability to recognize faces she has seen before (which allows her to say hallo to anyone by name)”. Its skin is created with mixture of silicone (Frubbet) and is very formable since Sophia can perform up to sixty-two face expressions, such as disgust, happiness, surprise, sadness and others. It has an electronic synthetic voice that enables it to talk, laugh or sing (Retto 2017).

## 4.3 Nanorobots

According to Jirsová (2019), the term nanotechnology was first mentioned in 1859 by Nobel prize winner Richard Phillips Feynman, who described nanorobots as robots that would be able to work at the molecular and cellular level. Durairaj (2012) remarks that nanorobots, as their name indicates, are robots that measure $10^{-9}$ meters and are constructed from nanocomponents. Nanorobots are introduced into the human body through the vascular system, or other cavities. The material used for its construction is not yet determined, because the developers are trying to find the most suitable one in terms of simplicity of construction and financial perspective, but according to Arun (2012), the most probable one is carbon. Carbon in form of diamond, or diamondoid nanocomposites is very strong and chemically resistant. Even though nanorobotics is being implemented into nowadays medicine, it is still a very new branch of robotics and is expected to be fully implemented into medicine within a period of five years. Compared to macro robots, nanorobots differ in size and in material used for their construction, but they have many similarities which could be eventually useful for application of nanorobots. According to Jirsová (2019), nano robots should be of great benefit to medicine as well as to other industries in the future. Arun (2012) emphasizes that nano robots could cause triggering of the immune system of a human body, but scientists deny this and claim that there is a very small chance because of the material used for their construction.

### 4.3.1 Construction

According to Ahmad (2014), different scientific disciplines must be considered in the construction of nanorobots. Bhore (2016) states that despite the outstanding progress made by scientists to date, the final version of the nanorobot working in the mechanical mode has not yet been completed. He further claims that “the greatest goal and perfect definition of nanorobot is to have a molecular entity entirely made of electromechanical components”

(p. 417). This statement is further specified by Ahmad (2014) and Arun (2012), who agree on this idea and add that carbon is the major element in the design and construction of mechanical nanorobots and other elements such as sulfur, oxygen, nitrogen and silicone are used for special purposes. Bhore (2016) explains that when it comes to the motion of the nanorobot, the ideal one should be able to move through the internal processing unit and fuel unit. However, there is a fundamental problem with the size of the fuel unit. Scientists and developers have not succeeded in reducing the fuel unit to a nanorobot size so far. The smallest assembled fuel cell was 5-6 millimetres, ranking it in the category of macro-robots, but not nanorobots.

### 4.3.2 Nanosensor

According to Bhore (2016), nanosensors are used to track cells and deliver essential information for further evaluation of the patient's current health state. The main purpose is therefore identification of cells that differ in parameters (volume, speed, velocity, pressure, temperature, etc.). Khanna (2012) gives an example of the use of nanosensors, where the detection of cancerous cells in the human body is detected and tracked by quantum dots injected into the human body. He describes the quantum dots as

> … crystals of semiconductor materials having sizes in the nanometer scale and emitting fluorescent radiation. These crystals are made of cadmium selenide (CdSe), cadmium sulphide (CdS), or indium gallium phosphide (InGaP) and coated with suitable polymers that safeguard human cells from toxic action of cadmium and also allow to attach molecules that enable tracking of cell processes and cancers. (2012, p. 33)

Khanna (2012) further explains that such application can be done using only nanosensors, since macrosensors or microsensors could harm the human body. Nanosensors are also very important when it comes to drug delivery, since the accuracy of the delivered product into the human body must be precise and each mistake could cause various complications in the future.

### 4.3.3 Navigation

Navigation of nanorobots is according to Bhore (2016) divided into two main categories: external navigation systems and internal (onboard) navigation systems. Robotics Bible (2012) states that for internal types of navigation systems different types of sensors such as spectroscopic, or chemical will be used. Chemical sensors will enable a nanorobot to reach the desired destination with the identification of diverse chemicals in human body. On the other hand, spectroscopic sensors will help reaching the desired destination by analysing different types of adjacent tissues. Bhore (2016) points out that external types of navigations are possible with the help of an ultrasonic signal which enables detection of its current position in the human body and its further establishment. Ultrasonic waves could be distributed either from an external source, or from the nanorobot itself. Waves could be afterwards detected using a sensor or other type of equipment scanning ultrasonic waves. Robotics Bible (2012) explains that different types of external navigation systems can be used. For example, MRI (Magnetic Resonance Imaging) device that will similarly to the ultrasonic system enable the surgeon tracking the nanorobot using waves. An advantage of MRI is its availability. MRI is in most hospitals, and therefore it is not necessary to buy other expensive equipment. Another type is radioactive dye, which is injected into the human body and with the help of a fluoroscope device the movement of the nanobot is tracked.

### 4.3.4 Power sources

Bhore (2016) and Robotics Bible (2012) divide power sources of nanorobots into two main categories: internal power sources and external power sources. According to Strickland (2020), one of the possible internal power sources could be created between two different conductors made up of different materials. The only condition that would need to be fulfilled is a gradient of temperature, which means that both conductors would have to be located at different positions in the human body. Both conductors create a thermocouple, which results in eventual voltage generation. This voltage generating process is called the Seebeck effect. This particular type of energy has a relatively good power-to-weight ratio, therefore it is perceived as a viable future source of energy. The other type of the internal power source can be created using the blood flow in the human body (Robotics Bible, 2012). Strickland (2020) explains that electrodes which are the part of the nanorobot could make use of electrolytes that occur in the blood stream and compose a battery that could power the nanorobot. A disadvantage of this type of the source is stated by Strickland (2020, n. p.): "While it might be possible to create batteries small enough to fit inside a nanorobot, they aren't generally seen as a viable source. The problem is that batteries supply relatively small amount of power related to their size and weight, so a very small battery would only provide a fraction of power a nanorobot would need." Another type of the internal power source could be created by chemical reactions, as Strickland (2020) observes, “the nanorobot would hold a small supply of chemicals that would become fuel source when combined with blood”.

Bhore (2016) explains that powering the nanorobot externally is possible either by the nanorobot being connected to an external power source by wires, or without any physical chain (optically). Systems connected by wires would need to move through the human body without creating any force or harm, but also withstand high pressure. Strickland (2020) states that the light transmitted through fibre optics would need to be transferred into electricity on board the nanorobot. Another system without a physical chain could be through microwaves. This system is thus expected to be used only partially, since it has some disadvantages that could cause harm to human body. Strickland (2020) also mentions that “microwaves are the least likely, since beaming them into a patient would result in damaged tissue, since the patient’s body would absorb most of the microwaves and heat up as a result.”

### 4.3.5 Application

Nanorobots will be due to their easy introduction into the human body an essential part of the diagnosis. According to Arun (2012), the future of nanorobots is very promising, since there are a lot of possible applications and uses for them. One of them is their assistance of the healing process of a damaged tissue by attaching to inflammatory cells or white blood cells. Its further use should include the treatment of tumours. Nanorobots should not only increase the accuracy of treatment of the disease due to more accurate introduction of medicaments, but they should also be able to detect it faster. The more accurate and thus more effective delivery of medicaments to a predetermined location in the human body should increase the chance of patient’s recovery. Another disease described in Uriarte’s (2011) work is diabetes, which mainly affects our and future generation. The number of people suffering from this disease or people with increased sugar levels is increasing every day. Since the correct level of glucose in the human body is very important for the proper functioning of metabolism, nanorobots should be able to detect excess or lack of glucose due to their built-in chemo-sensors. In addition, the nanorobot should transmit an RF signal that is displayed on the physician’s mobile phone or in the patient’s medical database. Nanorobots are also expected to find their use in dermatology. For example, cleaning pores, removing excess skin, skin oil, or moisturizing the skin should undoubtedly handle.

# 5 Elderly Care Robotics

Due to the aging society, there is an increasing demand for the robotic assistive systems that will not only enable the elderly people to live self-sustainable life, but also help the medical staff take care of other patients who may need their help even more. As Wilén and Ljungberg (2009, p. 20) state, “in Sweden, it is expected that about 25 % of Swedes population will be older than 65 years old by 2060,” therefore the robotic assistive systems are considered to be a possible solution to this problem. For this reason, researchers and scientists try to address this issue through creating robots that will be able to perform tasks as caregivers.

## 5.1 WAD – Walking Assist Device

According to Honda (2019) the WAD which stands for the Walking Assist Device that is a type of the robot which supports walking of a human and reduces expenditure of human energy when walking. As Cox (2013) explains, it also reduces stress in joints and muscles, and it is considered as a cross between the exoskeleton[15] and the chair. Honda (2019) further explains main components used: a hip frame made up of two motors that are placed at both sides of the device; a computer; a battery which provides the power for the device; and the other parts that enable the force to be transferred from the motors to the legs and thigh frame that help with initial movements of the user’s legs (see Figure 19).

Honda (2019) points out that the WAD detects movements of the human with built-in sensors and assists bending and extension of the user’s legs. It is intended for the people who have difficulties walking or for those with low mobility since it anticipates humans walking motion and aids their muscle activity. Since 1999, Honda Motor Company, Ltd. has continued to research these devices. Testing was carried out on humanoid robots. Based on the data collected during their research, Honda could afterwards improve this device significantly.

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[15] Exoskeleton refers to the external skeleton that supports and protects an animal’s body, in contrast to the internal skeleton of, for example, a human.

*Figure 19*. Walking Assist Device.
Adapted from: https://global.honda/products/power/walkingassist.html

## 5.2 The Mobility Scooter

“Mobility is one of the biggest issues and prerequisite for social participation and normal daily living, like shopping or visiting doctor,” Eck, Leutert and Schilling (2014, p. 4). For that reason, mobility scooters are used to eliminate these problems. Nowadays all kinds of mobility scooters are available to meet the client’s requirements (Mortenson 2015). The most important features that everyone should be interested in when looking for a scooter are:

1) ergonomic and adjustable seat that provides clients with comfort and ability to adjust the seat accordingly to their requirements;
2) the complexity of scooter control which can be either simple, advanced, or complex according to the client’s requirements;
3) stability, which is a key factor when it comes to people who have trouble walking;
4) reliability and safety;

### 5.2.1 Types of Mobility Scooters

According to Barton (2014, p. 4), “legally, mobility scooters are divided into two categories”. The first category is called “Class 2”. The scooters belonging to this category are designed and suitable only for the pavement use and are generally smaller than scooters that belong to “Class 3”. These smaller models can be easily collapsed down for transportation and are frequently used indoors and in the shopping centres due to their compactness. Its parts are commonly very easy to disassemble. The maximum speed allowed on the pavement is 6 km/h, but it must not be used on the road. The second category is called “class 3”.  Scooters belonging to this category are bigger than scooter from “class 2”, therefore are not suitable for indoor use, but are convenient for longer distances. Class 3 scooters can be used both on the pavement as well as on the road. Their maximum speed is generally higher (up to 15 km/h), but it is restricted to 6 km/h speed when driving along the pavement. Lights and indicators are mandatory when used on the road. Class 3 scooters also must be registered to DVLA (Driver and Vehicle Licence Agency) (Barton 2014).

### 5.2.2 Difference Between the Mobility Scooter and the Powered Wheelchair

Figure 21 illustrates a powered wheelchair, which is sometimes considered as a mobility scooter (Figure 20). Both are used mainly by people with movement disorder, or otherwise handicapped people and according to Pride Mobility (2019) they have many different features:

1) control (the biggest difference is that the scooter is equipped with a tiller and handlebars that are placed right above the front wheel, on the other hand, the powered wheelchairs are managed using a joystick to guide steering);
2) the powered chair is mainly used indoors, whereas the mobility scooter can be used indoors as well as outdoors;
3) manoeuvrability (the powered wheelchair can be maneuverer quicker than mobility scooter, on the other hand, the scooter has larger turning radii, so it is used mainly outdoors for activities like shopping);
4) number of wheels - mobility scooter usually has three to four wheels, whereas powered wheelchair has six wheels (two large drive wheels and four additional smaller wheels for better stability);
5) programmability (powered wheelchairs and mobility scooters control parameters can be finely adjusted; setting amount of acceleration or joystick sensitivity are in both types of carriages very similar, but the only difference is top speed, which is set by manufacturer and by law;

6) seating (the powered wheelchair has more options available when it comes to seating, whereas the mobility scooter has a generic seat for each type of the scooter);
7) price (mobility scooters are in most cases more affordable than powered wheelchairs);

*Figure 20*. The mobility scooter. Reprinted from: https://www.pinterest.es/pin/704391197944687363/

*Figure 21*. The powered wheelchair. Reprinted from: https://shop.mobilityworks.com/shop/power-wheelchairs/fullsize-power-wheelchairs/pride-jazzy-select-6-power-full-size-wheelchair/

### 5.2.3 Hardware

When constructing a mobility scooter, the base of this vehicle is one of the most important parts. According to Eck et al. (2014, p. 4), “the Trophy 4W, manufactured by Handicare GmbH, was used as the base vehicle”. The powered wheelchair maximum speed is up to 6 km/h, whereas scooter maximum speed is up to 15 km/h. Another useful piece of hardware is navigation which is constructed by company Navigon AG.

## 5.3 ASRO

ASRO robot is a robot, which serves a purpose of helping elderly, or temporarily health indisposed people. Some parts of a robot (arms, frame) are made of wood, to achieve overall lower weight. Undercarriage of an ASRO robot consists of three wheels (see Figure 22), which makes it impossible for a robot to climb up stairs or over object that are higher than five cm. Two of three wheels of an undercarriage are powered. Powered wheels have two hundred millimetres in diameter and third wheel which is not powered has one hundred millimetres in a diameter. When transferring an object, ASRO grabs an object with its arms consisting of gripping fingers. Maximum load capacity is up to three kilograms. To prevent a fall of an object, the ASRO robot is equipped with IR sensors, which enable him to grasp an object in the best possible position. Maximal speed of a robot is up to 0,61 m/s which is 2,19 km/h. Batteries inserted into robot are thirty-six amper hour batteries which enables a robot to function up to four days. When discharged, robot is equipped with a backup battery, which enables him to move back to the docking station. Dimensions of a robot are: 1.05m high, 0.45m wide, 0.5m long and its weight is approximately 30kg (Novotný 2016).

*Figure 22.* ASRO robot.
Reprinted from: http://www.zms.cz/cze/nabidka-sluzeb/vyvoj-a-vyroba-svarecek-pristupu-dochazky-solarnich-a-vetrnych-zdroju-napajecich-zdroju-robotu-a-kreativnich-hracek/osobni-roboti/

## 5.4 Care-O-Bot

Novotný (2016) points out that German company called Fraunhofer IPA is engaged in production robots called Care-O-Bot (as illustrated in Figure 23), which according to Graf, Hägele and Parlitz (2009), will help elderly to improve their life. Graf et al. (2009) further explain that

> out of 82 million people living in Germany today, according to numbers of the Federal Statistical Office, around 22 percent are seniors above 60 years. With the demographic development continuing, in ten years the number of people above 60 years old will comprise one quarter, in the year 2040 even 36 percent of Germany’s population. In an equivalent way, the number of people limited by diseases or handicaps will rise. (p. 1)

The first ever Care-O-bot is called Care-O-bot I which was constructed in 1998. Robot consisted of undercarriage and interactive touch screen. Care-O-bot I was able to reliably move around in a public environment and perform simple tasks such as transport of objects. On top of that, robot was able to act as a guide at several occasions, for example FESTO Annual Exhibition in 2001 (Novotný, 2016).

Successor of Care-O-bot I is called Care-O-bot II and it is a second prototype, which was built in 2002. The main difference and advantage Care-O-bot II had over his predecessor was addition of manipulation arm, adjustable supports for walking and ability to tilt its head which included sensors, two cameras and laser scanner for perception of environment. Manipulation arms were mainly used for grabbing objects such as plates, cups and bottles. Finally, mobility of second prototype was improved, as a robot was able to perform simple operations on its own.

The main vision of third generation of Care-O-bot was its aesthetic appearance, improved mechanism and components for everyday use. Care-O-bot III is managed via tablet, which is controlled by person. Another great feature of a Care-O-bot is reminding people of drinking enough fluids or reminding people when forget to take a medication. Reminders are being send to a tablet. Care-O-bot III is also capable of opening doors, for example when postman rings at the door, Care-O-bot opens the door and accepts a delivery. When it comes to construction of third generation of Care-O-bot, the robot is equipped with four wheels for its better stability (Novotný 2016).

*Figure 23*. Care-O-Bot.
Reprinted from: http://design-of-the-future.blogspot.com/2008/11/care-o-bot-can-take-good-care-of-you.html

# Conclusion

The aim of this bachelor’s thesis was to summarize the main information and introduction to the issues related to medical robots. Since this topic is not a well-known term for many people, some concrete examples of medical robots used in hospitals as well as in homes were listed.

The first chapter of the bachelor’s thesis focused on the beginning of the word robot and its gradual development, followed by three laws that a robot must comply with in order to be used in factories, medicine and other industries. The last part of the first chapter dealt with the first robot (Puma 560) which marked a great advance in the field of robotics.

The second chapter described the implementation of robots into medicine, their gradual development and the advantages that robots have over people. Moreover, the chapter provided a detailed description of the robot called da Vinci, which is currently considered to be the best known robot in terms of operations, Xenex robot, which is a robot used for disinfection of hospitals and other types of robots used in hospitals and homes.

Finally, this work discussed future types of robots that could be of great benefit to humanity. The thesis also mentioned robots like HeartLander and Sophia, which are robots that are already in the testing phase and will soon be part of hospitals.

Since our society is gradually aging, the assistance robots are increasingly needed, therefore, medical robotics related to this issue was examined as well. The last chapter described the concrete types of assistance robots, their programming and gradual development.

Overall, this work reveals that robots help us in most aspects of our lives. Medicine, as a very important industry, benefits greatly from the development of robotics, and therefore it is very important to constantly push the boundaries and improve these two closely related industries. From the first medical robot until now, medicine has changed beyond recognition. The greatest progress has been made in medicine over the past ten years. Although most robots are not perfect, we can say with some exaggeration that they may be in the future.

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