

Diplomarbeit

The influence of science fiction on medical science with emphasis on the musculo-skeletal system

eingereicht von

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(09.01.1989)

zur Erlangung des akademischen Grades

Doktor(in) der gesamten Heilkunde

(Dr. med. univ.)

an der

Medizinischen Universität Graz

ausgeführt an der

Klinik für Orthopädie und orthopädische Chirurgie

Universitätsklinikum LKH Graz

unter der Anleitung von

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Erscheinungsjahr: 2014 Nadja Glinik

Foreword

Jules Verne has predicted innovations like the helicopter, submarines, or space travel before these devices were even designed. The influence of other science fiction authors on medical science and vice versa seems to have increased during the last decades, reflecting various medical breakthroughs and the exponential growth in knowledge. While, for example, artificially grown organs were discussed in a 1968 novel, themes like nanotechnology and cloning dominated the ideas of future medical possibilities during the last 10 to 15 years. Most of those ideas that have been realized seem to have been described before in science fiction novels.

The aim of the present study was document previous predictions and achievements as well as to scan the creative work for future realizable ideas. A literature review on possible medical innovations found in science fiction literature was performed with a special emphasis on the musculoskeletal system. Nadja Glinik managed to achieve this goal to a great extent. We plan to put the most important findings into a concise publication. If you have an intense interest in this topic I am sure that you will enjoy reading this diploma thesis.

With best regards

Andreas Leithner

Danksagung

Mein besonderer Dank gilt meinem Betreuer, Herrn Univ.-Prof. Dr. med. univ. Andreas Leithner. Ihm ist es zu verdanken, dass ich mich mit einer außergewöhnlichen Thematik beschäftigen durfte. Er stand mir auch verlässlich mit seinem fachlichen Wissen zur Seite, und hat es nicht verabsäumt mich zu motivieren.

Ich möchte mich auch bei den Usern von scifi-forum.de bedanken, die mir durch interessante Diskussionen den Beginn meiner Arbeit erleichtert haben.

Auch meinen Eltern sei ein Dankeschön ausgesprochen, da sie mir das Studium überhaupt erst ermöglicht und mich immer unterstützt haben.

Abschließend möchte ich mich bei meinem Freund bedanken, mit dessen Hilfe ich in zahlreichen Gesprächen Zusammenhänge erkannt habe und zu Papier bringen konnte. Danke auch für die aufbauenden Worte, wenn mich Selbstzweifel zu übermannen drohten.

Eidesstattliche Erklärung

Ich erkläre ehrenwörtlich, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst habe, andere als die angegebenen Quellen nicht verwendet habe und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Graz, am 07.04.2014

Glinik Nadja

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Abstract

INTRODUCTION: In 2014, science fiction has found its way into everyday life. This thesis aims to illuminate the context between science fiction and scientific fact, concentrating on the field of orthopedics. Science studies phenomena of the material world by observation and experimentation and produces models of reality. Science fiction extends these hypotheses and projects them into the future. To satisfy the inexhaustible thirst for knowledge, we have to overcome dusty theories. Motivating was the fact, that some fictional ideas have become reality. Prospectively, we can be sure that even eccentric inventions and theories have the potential to serve as an inspiration for scientific research.

MATERIAL AND METHODS: Challenging was the commission to find science-fiction literature and movies with orthopedic reference. A message board was consulted for idea generation. Then it had to be validated if the described technologies were scientifically approved. This was done with the help of PubMed database and google search engine. Inclusion and exclusion criteria were evaluated for every single keyword. Due to topicality, not every science-fiction finding could be matched with scientific evidence. This was overcome by consulting newspapers and magazines, as well as TV-reports and documentaries. Alas, the scientific material dealing with the context of science-fiction and medical science was few and far between.

RESULTS: Most ideas and techniques existed in science-fiction before they found their way into reality. Exceptions are autografts and prosthetics. For the most part, researchers have taken science-fiction as an example. Illustrating is the technology of 3D printers, which helped to rebuild a lower jaw in 2012. The idea is based on the novel *Cantata 140* (1964). Also the invention of bone putty in 2009 originates in a science-fiction story from 1962. Supersuits, like seen in *Batman-Comics* (1939 – present), inspired engineers in 2010 to create exoskeletons, which help paraplegic people to walk again. An advancement in orthopedics which was feared to replace surgeons in the 1980s is ROBODOC. Larry Niven provides the template of autodocs in his story *Ringworld* (1970).

DISCUSSION: Comparing science-fiction with medical science may seem far-fetched. Nevertheless, the fact that some mundane inventions originate in fictional ideas proves that it is worth to cast an eye on science-fiction. The hypothesis that science-fiction has an influence on medical science can be supported. Progress in the 21st century occurs rapidly. Hence, science-fiction can be a source of ideas when obstacles in science are being met, by projecting existing ideas into the future. Endowed with new technologies, nothing

seems impossible. Ultimately, we have to overcome our fears, control our creations and always remember that only a human mind can take responsibility for actions.

EINLEITUNG: Im Jahr 2014 ist science-fiction Teil unseres täglichen Lebens geworden. Diese Diplomarbeit soll den Zusammenhang zwischen science-fiction und medizinischer Wissenschaft erläutern, mit besonderem Augenmerk auf das Fachgebiet der Orthopädie. Aufgabe der Wissenschaft ist es, Prozesse mit Hilfe von Beobachtung und Experimenten zu erklären. So entstehen Modelle der Wirklichkeit. Science-fiction projiziert diese Erkenntnisse in die Zukunft. Um unseren Wissensdurst zu stillen müssen angestaubte Ideen überarbeitet werden. Antriebskraft war die Tatsache, dass einige fiktive Ideen bereits Realität geworden sind. Vorausschauend kann gesagt werden, dass auch die fantastischsten Entwicklungen Anstoß für wissenschaftliche Forschung sein können.

MATERIAL UND METHODEN: Da sich nur wenige Arbeiten mit dem oben genannten Zusammenhang beschäftigen mussten zuerst science-fiction Ideen gefunden werden, die in einem orthopädischen Zusammenhang stehen. Zur Ideensammlung wurden science-fiction-Fans in einem Forum hinzugezogen. Die Quellen mussten wissenschaftlich evaluiert werden. Dazu wurde auf PubMed und mittels google-Suche nach den Entwicklungen gesucht. Ein- beziehungsweise Ausschlusskriterien wurden für jedes Schlagwort neu definiert. Da einige Errungenschaften so aktuell waren, dass es noch keine wissenschaftlichen Arbeiten dazu gab, wurden sowohl Zeitungen und Zeitschriften, als auch Reportagen und Dokumentationen zur Materialgewinnung hinzugezogen.

ERGEBNISSE: Viele Ideen und Entwicklungen existierten in science-fiction, bevor sie zum medizinischen Faktum wurden. Ausnahmen sind die Verwendung von Autotransplantaten, und die Erfindung von Prothesen. Meist dient science-fiction jedoch als Vorlage. Beispielhaft ist die Entwicklung von 3D-Druckern, mit deren Hilfe in 2012 ein Unterkiefer aus Titan produziert werden konnte. Die Idee basiert auf dem Roman *Cantata 140* (1964). Auch die Entwicklung von Knochen-Kit hat ihren Ursprung in einer 1962 entstandenen science-fiction Geschichte. Anzüge, wie der von Batman (comics 1939 – Gegenwart), inspirierten Elektroingenieure 2012 ein Exoskelett zu bauen. Revolutionär sollte 1980 in der Orthopädie die Einführung eines Roboters namens ROBODOC werden. Die Vorlage liefert Larry Niven in Form seinem Roman *Ringworld*, 1970.

DIKUSSION: Auf den ersten Blick mag der Vergleich von science-fiction mit medizinischer Wissenschaft absurd erscheinen. Die Tatsache, dass einige alltägliche Technologien ihren Ursprung in science-fiction haben beweist jedoch, dass es sich lohnt hellhörig zu werden. Die Hypothese, dass science-fiction einen Einfluss auf die Wissenschaft hat konnte also bestätigt werden. Der Fortschritt im 21. Jahrhundert ist unaufhaltsam. Science-fiction kann eine Quelle für neue Denkansätze sein, indem bereits existierende Ideen weiter gedacht

und in die Zukunft projiziert werden. Neue Technologien ermöglichen das Udenkbare. Schlussendlich gilt es noch, unsere Ängste zu überkommen und uns bewusst zu werden, dass am Ende jeder Maßnahme immer ein Mensch steht, der die Verantwortung trägt.

1. A general introduction

1.1. Defining “science fiction”

What exactly do we understand by *science fiction*? In its early days Isaac Asimov defined it as “that branch of literature which is concerned with the impact of scientific advance upon human beings (*Modern Science Fiction*, 1953)” (1). Pamela Sargent dubbed it “the literature of ideas.” (1) Authors of science fiction want to give the reader an idea about alternative worlds and futures. By doing this they have inspired loads of minds to take a step beyond rationality and come up with fantastic innovations, some finding their way to everyday life in 2012.

In the 17th century, who would have thought it possible to communicate over large distances by somewhat other than correspondence? Later on people couldn’t imagine their telephones without wires, whereas nowadays we find it hard to spend one day without being contactable permanently. (1)

During the last centuries ideas have not only been passed on orally, but finally found their way to written word. Technical evolvement is only part of the influence science fiction had on society. More and more subgenres developed, such as hard sci-fi, an extremely specific and accurate category of science fiction providing a lot of predictions which turned out to be true. What should be of more interest in this thesis is the subgenre of cyberpunk. “The cyberpunk genre emerged in the early 1980s; combining cybernetics and punk, the term was coined by author Bruce Bethke for his 1980 short story *Cyberpunk*” (2). Artificial intelligence and prosthetics play an important role in cyberpunk and will be discussed in this thesis. One may also consider the genre of biopunk, which deals with the progress in the fields of biotechnology and the problem of being able to decipher genetic information. (2)

It cannot be denied that long before the term *science fiction* even existed, mankind came up with their own fantastic explanations for things they were not able to understand yet due to the lack of scientific progress. These became known as *myths* or *legends*. A legend is defined as “a story coming down from the past; especially: one popularly regarded as historical although not verifiable” (3).

1.2. A short history of surgery

The history of medicine dates back as far as the history of manhood and is full of myths and legends. The focus of this paragraph will be on the first steps of surgery, since this should be the main issue in the following chapters.

First surgical techniques mostly had the aim to treat injuries and traumas. Archeological device gives reason that the first surgical procedures performed have been trepanations and the setting of bones. Cave paintings and human remains from Proto-Neolithic and Neolithic times provide evidence. Excavations of the banks of the Dnieper river (flowing from Russia to the Black Sea) even show the existence of human trepanned skulls dating back to the Mesolithic times. The Sumerians should not only be remembered for creating the oldest form of writing, but for their contributions to medicine as well. Urlugaedin (4000B.C.) is referred to as the first known surgeon. His personal seal shows two knives surrounded my medical plants. In Nineveh, known as Mosul today, archeologists old fashioned scalpels made of bronze and obsidian were found. (4).

Even though first steps in surgery may have evolved in many places simultaneously, the *Father of Surgery* is to be found in India and known by the name of Sushruta (600 B.C.). Notably is his contribution to plastic surgery: he invented the technique of forehead flap rhinoplasty. This technique was important in these days, because thieves and other criminals were punished by amputating their nose. It can be found almost unchanged in present day surgery. The first descriptions of operational procedures are found in the Sushruta Samhita. It also contains descriptions of instruments as forceps, pincers and even old fashioned cauteries. (4) The Egyptians play another important role. Not only were they were inventive in fields of technics and astronomies, but also did they hold important progress in medicine. They used copper for their surgical instruments.

The Aztecs treated broken bones, by extending and adjusting it. If a more sturdy fixation was needed, they performed a medullary fixation by inserting a branch into the cavity of the bone. (4)



Roman marble statue, showing Asclepios Fig,1

Of course, ancient Greek medicine should not be left out, though they borrowed a lot from the Egyptians. Greek mythology states Apollo as the God of Medicine as is his son, Asclepius. It is the famous rod entwined by a snake that still is a symbol of medicine. (4) Figure 1 shows a Roman statue of the God of Medicine.

Note that all these operations were performed without anesthesia. The use of narcosis and the knowledge of infection came about in the mid to late 1800s. (4)

Myths embower the twin brothers Cosmas and Damian. Born approximately in the 3rd century A.D., they held the profession of physicians and are known to be early Christian martyrs, as they did not recant and were beheaded. Their most miraculous contribution to medicine was the replacement of a diseased leg by the leg of a deceased moor. They hold the patronage for surgeons, physicians, dentists and pharmacists. (5)

Another important patron saint is Saint Luke the Evangelist. He was the first Christian physician. Of course, the Bible holds a load of fantastic and wondrous stories of healings, but as there is no evidence, they shall be excluded in this thesis.

Where is the relation between all this historical facts, myths and oral traditions and what we understand by modern science fiction? It is the fact, that way back then people did not have the knowledge we have today and made Gods, demons or faith responsible for what was happening. Even with their bodies and health. In Chinese mythology demons are related to disease; the ancient Greek physician Hippocrates states, that illness emerges due to an imbalance of the four humors (yellow bile, black bile, blood and phlegm). Though lacking knowledge, they craved for explanations. And the true inventors and scientists of back then were visionaries of a better future. They were not afraid to look out of the box, often sacrificing their own life for their ideas. Is there so much difference now? Science fiction is often greeted with smiles. But as a matter of fact, these preposterous ideas animate us to open up our horizon and take a step towards faster, better, stronger.

1.3. Authors of science fiction

Let us take a look at the authors of science fiction, some of them having a meaning to everyone of us, either having heard of them in school or being so tightly linked to that

genre that they are mentioned in the same breath. Others you might have never heard of; but they seem of special importance as they are profound physicians.

Medicine does not play the most important role in science fiction, but seems to be part of a lot of stories. Why is that? Science fiction explores our hopes and fears; we all have to face illness, injury and loss sooner or later in life. It is tempting to find a cure for an incurable seeming disease. Or regrow fully functional limbs; obtain everlasting youth or playing a trick on death. An interesting note seems to be the fact that all these amenities do not come without a cost.

As for authors, Jules Verne, whose portrait can be seen in Figure 2, will start. This Frenchman is known to be a pioneer of science fiction even in his times. His novels have been imitated, made into film and cited so many times that it seems impossible not to have come in touch with his work. In his novel *Twenty Thousand Leagues Under The Sea*, published in 1870, a story about Captain Nemo and his submarine Nautilus, he gives a detailed description of submarines that were not to be built until the First World War.



Jules Verne Fig.2

“Here, M. Aronnax, are the several dimensions of the boat you are in. It is an elongated cylinder with conical ends. It is very like a cigar in shape, a shape already adopted in London in several constructions of the same sort. The length of this cylinder, from stem to stern, is exactly 232 feet, and its maximum breadth is twenty-six feet. It is not built quite like your long-voyage steamers, but its lines are sufficiently long, and its curves prolonged enough, to allow the water to slide off easily, and oppose no obstacle to its passage. These two dimensions enable you to obtain by a simple calculation the surface and cubic contents of the Nautilus. Its area measures 6,032 feet; and its contents about 1,500 cubic yards; that is to say, when completely immersed it displaces 50,000 feet of water, or weighs 1,500 tons.” (6)

What clearly comes to my mind when thinking of the oldest rememberable piece of science fiction is *Frankenstein* (published in 1818) by Mary Shelley. The idea of building artificial life due to a scientific experiment is as terrifying as ingenious. Mary Shelley drew some of her concepts from the ideas of galvanism, which started to get popular at times.

The rainy weather in her hometown, the nascent idea of galvanism and a fondness of ghost stories inspired the young lady. In the first screen adaption in 1931, Boris Karloff impersonates Frankenstein's monster and leveraged his career. Figure 3 shows a screenshot of Karloff.

“I saw the pale student of unhallowed arts kneeling beside the thing he had put together. I saw the hideous phantasm of a man stretched out, and then, on the working of some powerful engine, show signs of life, and stir with an uneasy, half vital motion. Frightful *must* it be; for *SUPREME*LY frightful would be the effect of any human endeavour to mock the stupendous mechanism of the Creator of the world.” (7)

Surely, this novel reflects the hope to go beyond borders and insatiable curiosity some scientists can call their own. Yet, the story illuminates the problems that come along as well. Nevertheless, maybe it was this unfortunate experiment that made surgeons try their best at transplanting not only human organs, but also limbs.



Boris Karloff as Frankenstein's Monster Fig.3

Among the authors of science fiction, a physician stands out. Stanislaw Lem, born in Lemberg (now known as Poland). His interests were in the field of psychology which shows in his works. (8)

In his novel *Solaris* (1961), the protagonist Kelvin faces his deceased wife on the trip to a new planet, later realizing that it is only a realistic 3D image evoked by his thoughts and feelings.

Another natural scientist who found the profession of the author appealing was the Russian Isaac Asimov. His special interest applied to artificial intelligence. The short story

Robbie (1940) is the first in a long line of robot stories. For Asimov the old robot stories followed the so called *Frankenstein-pattern*: robots get build and then destroy their builder. He pursued to change that and developed his *Three Laws of Robotiic*, embedded in his stories:

1. "A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. "A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
3. "A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws" (9)

Herbert George Wells (H.G. Wells) is one of those authors being mentioned in one breath with Jules Verne. The text of the novel *The Island of Doctor Moreau* (1896) relates the story of Edwards Prendick, who stranded on the Island of Doctor Moreau, who creates beings able of feeling out of different species of animals.

1.4. Special doctors

Having passed some time getting to know the *Fathers of Science Fiction* and a physician who took pleasure in writing, two grand characters of science fiction will be introduced, with Holodoc (Star Trek Voyager) leading the way.

The Holographic Doctor is in fact a program designed by another Star Trek character, Dr. Louis Zimmermann. "He is programmed with the medical knowledge of forty-seven of Starfleet's finest physicians and the collected medical information of three thousand cultures." (10)

Also of high prominence is Dr. Leonard McCoy from Star Trek. Remarkable is the fact that even in science fiction doctors tend to get idealized as irascible, arrogant and have a weakness for alcoholic beverages.

1.5. Popular themes in science fiction

What is the first thing that comes to your mind when you hear *science fiction*? Flying cars? Super intelligent human-looking robots? Aliens? Or time travelling? The next few paragraphs will focus on some of the most common subjects in science fiction.

1.5.1. Robots

The progress in the field of technology cannot be denied. The advances made in the fabrication of goods have been enormous. Also the products themselves have changed: take a look at cars 100 years ago; or the beginnings of the modern telephone, which have taken place in the early years of 1800. Technical progress is happening every day. And to some extent all our technical devices at home are somehow brothers of the robot.

The robot in science fiction had its first appearances in the early 19th century. It seems like the Industrial Revolution had lend wings to the minds of some authors.

In *A Wife Manufactured to Order* (1895) by Alice W. Fuller a dialog as follows can be read:

"Now, young man, what can I do for you? Want a life-companion, a pleasant one? Man of means, no doubt, and can enjoy yourself; a little fun now and then with the boys and no harm at all -- none in the least... Now, sir, I can get you up any style you want -- wax, but can't be detected."

"Do you mean to say you manufacture a woman out of wax, who will talk?"

"That's just what I do; you give me the subjects you most enjoy talking upon, and tell me what kind of a looking wife you want, and leave the rest to me, and you will never regret it. I will furnish as many 'phones' as you wish; most men don't care for such a variety for a wife -- too much talk, you know." (11)

It is the description of a robot, indeed. One could even argue if it was Mary Shelley, who was the first to come up with a robot-story, by saying it was artificial life Dr. Frankenstein created.

The term robot is used for mechanical devices that is able to act automatically. It can be of different appearances. In some fields they have replaced humans as workers. But this work will not focus on machines, but robots that actually look like humans. By other words: *androids*.

Important to notice, most of the time it is a human being that has to program a robot, as we understand it. In science fiction, robot populations often come from another planet or universe without the intervention of humans in their evolution. Important also the difference of the terms *android* and *cyborg*: whereas an android is an artificial man/woman, a cyborg describes a man/woman with mechanical enhancement. Cyborgs will be dealt with in the more specific chapter of this thesis. (2) “The term *droid*, coined by George Lucas for the original *Star Wars* film and now used widely within science fiction, originated as an abridgment of *android*, but has been used by Lucas and others to mean any robot, including distinctly non-human form machines.” (12)

But androids are no fiction any longer. Chinese and Japanese scientists have successfully developed human-looking machines. “The Intelligent Robotics Lab, directed by Hiroshi Ishiguro at Osaka University, and Kokoro Co., Ltd. have demonstrated the Actroid at Expo 2005 in Aichi Prefecture, Japan.” (12) Actroid is a *gynoid*, a female android. Its skin is made of silicone



Hiroshi Ishiguro and his twin robot Fig.4

and its mimics and gestures seem so realistic due to air actuators placed at several different places in its body. In 2006 an even better model has been developed, DER2. Like Actroid it has the appearance of a woman. Its movements are even more fluent, the repertoire of expressions amplified. Both robots are able to imitate human behavior, but once again, it is humans they are being programmed by. (12) The Korea Advanced Institute of Science and Technology (KAIST) released a similar project in January 2005: the HUBO (humanoid robot). They even created an *Albert HUBO*, with Albert Einstein lending his face and voice to the robot. Thirty artificial facial muscles help 1955 deceased Albert Einstein come to life again.(13) At the Ars Electronica Centre, Hiroshi Ishiguro introduced his twin robot called Geminoid I-1. Figure 4 shows both of them.

Of course these inventions were not made without any ulterior motive. We tend to come up

with ideas to make daily routine more comfortable. Robots, and androids, are built to take unpleasant work off our shoulders.

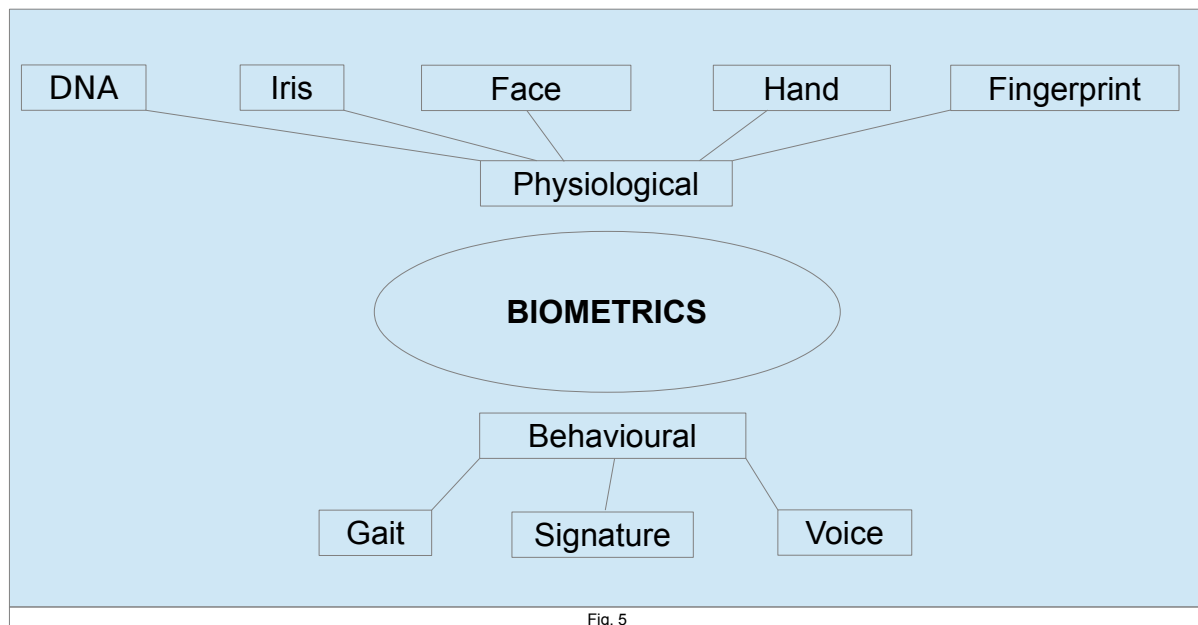
Science fiction yet provides another interesting aspect of a future with robots. In *A.I. – Artificial Intelligence* (2001) or *I, Robot* (2004) mankind has to face the problems an android population poses.

1.5.2. Biometrics

To keep to the point I want to go on with another mechanic-related subject: biometrics. “The goal of biometric authentication is the automated verification of identity of a living person by providing over some unique feature which only he possesses.” (14) In biometrics, physiological and behavioural aspects can be distinguished, as shown in Figure 5. This chapter will concentrate on physiological biometrics, meaning the distinction of individuals by their voice, DNA or finger prints. (14) Biometrics as we understand it today has had its revolution in the 20th century. “Biometrics has been science fact rather than fiction since 1901, when Scotland Yard and the New York Civil Service Commission began using fingerprints for identification. In 1930, the FBI set up its first national fingerprint file.” (15) Still, finger prints are the most mature biometric technology and even used it places like Walt Disney World in Florida, to make sure that a ticket is used by the same person. Scenes like the one in *Enemy of the State* (1998), where recordings of an observation camera are linked to a computer system that simultaneously displays the persons identity, are a far cry from reality.

Nevertheless, technology advances so fast that scenes from the movie *Minority Report* (2002) are possible. In the movie, which takes place in 2054, Tom Cruise is pursued by devices, that scan his eyes and match his identity. To escape the law, he gets his eyeballs replaced but keeps the original ones in order to get access to his former workplace. Even nowadays biometric systems can distinguish between living and lifeless eyes, fingers, etc., which makes the technology in the movie look outdated. We are surrounded by biometrics in our every-day life without even recognizing it: we have finger scans instead of laptops on our computers; iris recognition in our digital camera; hand geometry systems for access to airports (seen in San Francisco) or to track working hours. (15)

Once more one could argue if this achievement is a blessing or curse. Of course it would mean a great step forward in crime detection. But at the same time there are problems coming along, which will make us feel like Winston Smith in George Orwell's 1984 with *Big Brother* watching us all the time. Plus: Biometric technology is not flawless. "Fingerprints, for example, may never change, but dry skin, wet skin, dirt and cuts can obscure features." (15) We grow older, which shows in our faces and even irises. Lighting conditions are not always the same, which causes troubles as well. And as technology advances, so does the creativity of criminals. They use high resolution photographs of fingerprints or irises to get access. It is a cat-and-mouse game. Additionally, criminals have the opportunity to attack the databases with the recorded information of thousands of individuals. Maybe that is the reason why some people remain suspicious. (15)



1.5.3. Nanotechnology

An even more popular topic in the science fiction genre one might not think of in the first place is nanotechnology. Being first mentioned in *There's Plenty of Room at the Bottom*, a talk given by physicist Richard Feynman in 1959, it has found its way into our life no matter in the fields of surface coating or pharmacology. First theories date back as far as 1881, when Nikolai Leskov wrote in *The Tale of Cross-eyed Lefty from Tula and the Steel Flea* :

“If you had a better microscope that could magnify five million times’, he said, ‘you would that each gunsmith had put his name on the shoes he made so that you know which Russian craftsman made which shoe.’” (16)

In Feynman's *There's Plenty of Room at the Bottom* (1959) the idea of “swallowing a doctor” is presented: the principle would be a tiny swallowable surgical robot, which contains a set of small scale tools, which can be navigated by a real doctor outside the patient's body. Other representatives are the nanites from *Star Trek*. They are small enough to enter into cells. In reality, scientists already carry out research in this field. Not only do nano-drugs seem desirable, which would find the target independently and reduce side-effects, but also the next step, a nanobot for surgery, is an interesting device. Via a magnet, the miniature robot could be navigated to the place where surgical intervention is needed.

The origins of this idea can be found in the story *Waldo* (1942) by Robert A. Heinlein. The talk left a fleeting impression. “K. Eric Drexler later took the Feynman concept of a billion tiny factories and added the idea that they could make more copies of themselves, via computer control instead of control by a human operator, in his 1986 book *Engines of Creation: The Coming Era of Nanotechnology*.” (17) Hollywood seems to never get tired of refining nanotechnology ideas. In *I, Robot* so called “nanites” are being used to bring the supercomputer V.I.K.I (Virtual Interactive Kinetic Intelligence) to a halt and thereby wipe out artificial intelligence. *G.I. Joe: The Rise of the Cobra* (2009) is a movie in which the main characters need to save the world from nanobots, called *Nanomites*.

But what exactly is nanotechnology and which scenarios have actually come true (focusing on the fields of medicine)?

“Nanotechnology (sometimes shortened to *nanotech*) is the manipulation of matter on an atomic and molecular scale.” (18) Current research involves nanomaterial, some of them being used in medicine. In mice gold nanoshells have been used to detect and treat cancer; liposomes are being used as vaccine adjuvants and to improve drug transport. The purpose is to improve bioavailability. But of course obstacles appear as science improves.(18)

With the progress of nanotechnology nanotoxicology develops in parallel. The source of

concern is simple: when materials appear as nanomaterials, no one can be sure that they behave in the same way the parent material does. For example: gold is considered to be an inert material; but when nanoparticles of gold come into contact with oxygen they burst into flames. “The worst case position is clear: any material might be toxicologically active, or more active, in an unpredictable way [...] when presented to the body in nano-form.” (17)

In conclusion, even though nanotechnology is expanding rapidly we should be aware of the risks it poses. This is not as easy as it seems as nanotoxicologists do not even know about the risks they should be looking for, as the science of nanotechnology itself is so new. Once more, we have to face the question whether it is a blessing or a curse. (17)

1.5.4. Time travelling

Another popular vision of science fiction is the ability to move places in just a few seconds. In other words: to beam. Or the ability to time travel. Whereas magicians often want to make us believe that they are able to travel hundreds of kilometers in some seconds, science fiction delivers (hypothetical) technological facts. The process of beaming therefor is also called teleportation. First being mentioned in 1855 by Sydney Whiting in his novel *Helionde*, it has been a common theme in sci-fi literature. (19) In fairy tales, like *Aladdin*, teleportation reserved to djinns. In the stories of *Harry Potter*, time travelling and teleportation can be found. But it was not until *Star Trek: The Original Series* that teleportation began to boom. The phrase *Beam me up, Scotty* has become a winged word. Until 1997 researchers were not able to beam matter. Merely Quantum Transportation is possible. In this process a qubit (the basic unit of quantum information) can be send from one location to another. Unfortunately, this process cannot be used to communicate, as it does not transmit information in the classical sense but needs to be processed. The distance of transportation is limited as well. “Presently, the record distance for quantum teleportation is 143 km.” (20) This range still remains world record and was achieved by a group of physicians, headed by Anton Zeilinger. A photon was sent from the Canary Island La Palma to neighboring Tenerife. Zeilinger states, that this experiment shows what can be possible in the future: Communication via Quantum Transportation would become bugproof. (20)

Time travelling can form the main plot of a story or be merely part of it. *The Time Machine* (1895) by H.G. Wells is an early story that uses the theme of time travelling. But it can be found in ancient mythology as well. Indian mythology mentions the story of King Revaita, who travels to a different world to meet Brahma, the creator. When the King finally returns to earth, he has to realize that many ages have passed during his stay in the different world. (21) Even in Charles Dickens *A Christmas Carol* Ebenezer Scrooge is being moved back and forth in time to take a look at his past, present and future. *Harry Potter and the Prisoner of Azkaban* offers another interesting method of time travelling: Hermione Granger, one of the main characters, gets a time-turner in order to re-live her classes.

By including time travelling into the story's plot, the story can be changed for good or evil. To prevent a bad end some authors came up with guardians of time, as for example in Isaac Asimov's *The End of Eternity*. As in *A Christmas Carol*, the time travels let Ebenezer Scrooge see what might happen if he goes on the way he did. Thereby a bad future is prevented. The movie *The Butterfly Effect* (2004) shows the impact even small actions in our life have on our future. (22)

Alas, time travels like beaming are far from reality. The only hope scientists can give us are time travels of the mind.



Time Magazine Cover March 1997 Fig.6

1.5.5. Cloning

Let us move on to a more scientifically verified topic: Human cloning. The term *cloning* refers to the process of producing pieces of identical genetic information. Cloning is something happening all the time all around us. Bacteria can reproduce that way; it even happens in our body: DNA in cells is replicated constantly. (23)

When we come across cloning in science fiction we often have to face questions of identity or ethics. Aldous Huxley's novel *Brave New World* (1932) makes human cloning a subject of discussion and also argues its problems. Star

Wars presents the issue in a different way: an army of clone troopers is being produced. *Dolly* is maybe the first thing the general population associates with cloning. Via the process of nuclear transfer, Dolly was the first mammal to be cloned from an adult somatic cell in 1996. (23) The progress was so impressing, that Dolly, the sheep, became a symbol for cloning and cover-model for Time Magazine, shown in Figure 6.

In science fiction cloning can be used to reawaken historical figures, such as Adolf Hitler in *The Boys from Brazil* (novel 1976, film adaption 1978). The movie *The Island* (2005) brings cloning to the boil: Clones are being produced in order to function as organ donors. At this point, problems, ethical issues and criticism come into effect. Artificial human cloning is an extremely controversial issue. (24)

The aim of human cloning cannot only be a reproductive or therapeutic one, but gives insight to one of our greatest fears: death. Human beings have occupied themselves with the limitations of life ever since. We dread the loss of beloved ones; some people cannot live with the fact that the Earth will someday turn without them and therefor would do everything to never stop existing.

Some fictional figures are immortal but had to pay a high price: vampires are known to be undying. They can only die by a silver bullet, a stake through the heart or sunlight-exposure. Ghosts are immortal as well, even though they are just a poor imprint of their former selves. Horcruxes exist in *Harry Potter* as a possibility to gain immortality, by splintering one's soul. *The Elixir of Life* is also a common used subject. Though it seems desirable on the one hand, the *undead* in science fiction have a bad record. In this context immortality is seen as a bane.

Looking back a few decades, when people tended to die at the age of 30 or 40, one might think that science is progressing so fast that immortality can be achieved indeed. But it has not yet been possible. Nevertheless, some people do not let them stop that easily. The latest idea is digital immortality. It poses "a kind of Plan B if bioscience fails to deliver an actual biological immortality"(25), says Stephen Cave, author of the new book *Immortality*. He adds:

"So your brain is scanned and your essence uploaded into a digital form of bits and bytes, and this whole brain emulation can be saved in a computer's memory banks ready to be brought back to life as an avatar in a virtual world like Second Life, or even in the body of an artificially intelligent robot that is a replica of who we were." (25)

Conclusively, even biological immortality would not save you from getting run over by a bus the next day. (25)

2. Healing and reconstructing bones

William Stryker: We're going to make you indestructible - but first, we're gonna have to destroy you. You remember what we were looking for in Africa?

Logan: I remember.

William Stryker: Well, I found it. It helped us to create a metal compound so strong, that you'll be able to withstand virtually anything. It's called adamantium. I can't put Victor down myself, Logan. To kill him, you'll have to embrace the other side, become the animal.

Logan: Let's do this (26)



2.1. Bone healing

This quote displays the beginning of the metamorphosis of one of the most impressive characters in science fiction. It is the story of Logan, better known as Wolverine. Widely known due to the screen adaption of 20th Century Fox. Wolverine's story originates in comic books in 1963, published by Marvel Comics.

In the cited movie scene above, Wolverine gains some abilities that render him rather interesting for orthopedic investigation. His skeleton, which is perfectly human although Wolverine himself is considered to be a mutant, gets destroyed and replaced by a new one made of adamantium. Part of his skeleton, including his deadly claws which can shoot forth from his underarm, can be seen in Figure 7. This transformation though has only been possible because of his special mutant ability to heal rapidly. The only way to kill him would be to behead him and place his head out of reach of his body. Adamantium is a fictional, very hard metal or alloy. The name "derive(s) from the Greek word ἀδαμastos (*adamastos*), meaning 'untameable'". (27) In ancient history the term has been used to

describe very hard material. In recent culture we come among it in William Shakespeare's "A Midsummer Night's Dream" (1596), J.R.R. Tolkien's "The Lord of the Rings" (1954) and the computer game *Final Fantasy* (1987 – present). (27)



Adamantinoma of the tibia Fig.8

Still, the observant reader may have come across a similar term in oncology. In this field of medicine, a low-grade, malignant biphasic of the tibia or fibula is known as adamantinoma of the long bones. This tumor, which is of epithelial origin, is extremely rare and expands in an aggressive osteolytic pattern. Histologically it may be difficult to distinguish between osteofibrous dysplasia and adamantinoma. In a x-ray an adamantinoma it is characterized by a well circumscribed osteolytic lesion, which poses the risk of mistaking it for an osteofibrous displasia. These characteristics can be seen in a x-ray of the lower limb in Figure 8. Macroscopic it impresses as a grey and white mass. Clinical symptoms can be swelling and pain in the area of the tumor. Other characteristics are patient age and history. A slight predominance is found in male

patients. The general treatment is a wide surgical excision. (28)

Unfortunately we do not have access to adamantium or anything alike, nor are we able to destroy ones skeleton to fully replicate it within minutes. But science has made some progress considering bone healing during the last years. The following will outline some of the recent achievements.

2.2. Bone tissue reconstruction and bone repair

Bone defects appear due to different causes. It may be because of trauma, bone disease or infection. Additionally bone tissue can get destroyed by cancer. Most popular reconstruction techniques nowadays include autografts, allografts and prostheses.

If the patient himself/herself is the donor of a tissue, it is called autograft. This seems to be the best choice for transplantation, in the narrower sense also bone transplantation. Bone autografts posses osteoconductivity, osteogenicity, and osteoinductivity, which are the three elements for new bone growth.(29) "Osteoconduction refers to the ability of the graft to ensure adhesion, survival, and proliferation of osteogenic cells, providing an

interconnected structure through which new cells can migrate and new vessels can form. An osteogenic graft, on the other hand, implies the presence of osteoblasts at the fusion site that are able to synthesize new bone directly. Finally, osteoinduction refers to the ability of a graft to induce non-differentiated stem cells or osteoprogenitor cells from the surrounding tissue to differentiate into bone-forming osteoblasts.” (30)

For autografts surgeons mostly use the iliac crest because it represents a good quality and quantity of bone. Nevertheless, the harvesting is limited, painful for the patient and means extra surgical time. In addition, it poses the risk of infection. (29)

On the other hand, allografts, which are tissues transplanted between non genetically identical individuals, pose the risk of infection and rejection due to immune response. Therefore fresh frozen or freeze dried allografts are used. Fresh frozen allografts have the advantage of being more osteoconductive, plus they offer better mechanical properties, whereas the disadvantages are a higher risk of infection and rejection. Freeze dried allografts do not possess these problems, because they do not produce immune responses, but they lack stability and osteoconductivity. (29)

Because of the emerging problems with autografts and allografts, scientists have been searching for alternatives. “The ideal bone graft substitute should be osteoconductive, osteogenic, osteoinductive, biocompatible, biodegradable, structurally similar to bone, easy to use clinically and cost-effective.” (31) Investigations therefore focus on “on osteoinductive growth factors [such as bone morphogenetic proteins (BMPs) ...], osteoconductive scaffolds (such as calcium phosphate and other ceramics), or a combination of the two.” (32)

2.2.1. Bone grafts – single composites

A large variety of bone-graft alternatives is already known. The majority consists of natural or synthetic biomaterials, that are build into scaffolds. They provide the perfect properties for migration, proliferation and differentiation for new bone tissue. Collagen, ceramics and glass ceramics are mostly used. Whereas ceramics class with synthetic scaffolds, collagen (especially collagen type I) is the most common protein in the extracellular matrix (ECM) of the bone. Both substances alone do a poor job as graft material. But the combination makes them suitable. (29)

These present strategies are satisfying, but nowhere near exceptional. “A promising approach that could overcome the limitations of current therapies for producing synthetic grafts relies on tissue engineering techniques. Bone tissue engineering techniques aim to combine the use of cells (for osteogenesis) seeded in three-dimensional (3D) biocompatible scaffolds (for osteoconduction and vascular ingrowth), with appropriate growth factors (for osteoinduction), in order to generate and maintain bone.” (33) The ideal scaffold, cells that are able to differentiate into bone cells and the regulation of growth factor (cytokine, respectively) delivery are a prerequisite. (33)

The 3D scaffold should resemble as much as possible the one of the natural bone, which is a composition of inorganic-organic tissue made up of hydroxyapatite (HA) and collagen fibers. Lately new fabrication methods have evolved, including “phase separation, melt-plotting, template synthesis, electrospraying, electrospinning, and the recently developed electrohydrodynamic printing.” (34)

Metals, ceramics and polymers are the most used biomaterials in bone tissue engineering. (29) One big advantage of metals is their mechanical stability, though their lifespan is limited to 10-15 years after implantation, due to poor osteointegration. Nano-structured surfaces have been able to improve this property. This modification increases surface roughness, which increases protein adsorption, cell adhesion, proliferation, and deposition of calcium-containing mineral. Titanium seems to be best suited for bone tissue engineering. It is inert, has very good mechanical properties and on the back of this it is biocompatible. By roughening its surface its qualities can even be improved. It can be done either by removing material from the surface (subtraction mechanism) or by adding particles to it (additive mechanism). Examples for the first technique would be blasting or acid etching. The additive mechanism creates a surface with knobs. It is done by means of titanium plasma-spraying (TPS). In this process, titanium powders get injected into a plasma torch at very high temperatures. Once on the surface of the implant, the particles condense and melt together. The 30 µm thick layer that is formed thereby increases the surface. (29) It ensures a higher cell attachment and proliferation. Additionally, a study of Brett and Co. shows that the degree of surface roughness of titanium influences the genes expressed by bone cells. (35)

Blasting is a technique which projects ceramic particles “into the implants through a nozzle at high velocity by means of compressed air, and different surface roughnesses can

be produced on titanium implants according to the size of these ceramic particles.” (29)

Another commonly used material in tissue engineering is ceramics. Not only is it biocompatible, but also bioactive. A bioactive substance is a substance that is “able to support cell adhesion, proliferation, and differentiation.” (29) Calcium orthophosphates (such as HA and tricalcium phosphate (TCP)) show similarities to the mineral components of human bone and are so of special interest. Latest studies show that nano-sized orthoceramics have even better effects on cell adhesion, proliferation and calcium deposition. Among the most used nano-sized orthoceramics is nano-hydroxyapatite (nHA). It can be produced via electrospraying or electrodynamic printing. (29)

The last group of materials used in tissue engineering are polymers, which can either be natural or synthetic. Among natural polymers polysaccharides (alginate, chitin/chitosan, hyaluronic acid and derivatives) and proteins (collagen, fibrin gels, silk) can be found. Nevertheless, synthetic polymers gain attention because they can be fabricated and therefore be given different properties. They include poly(L-lactic acid) (PLLA), poly(glycolic acid) (PGA), and their copolymers such as poly(lactic-co-glycolic acid) (PLGA). As for ceramics, nanotechnology has a positive effect on polymers as well. It is the improvement of cell attachment that adds to the benefit. “At this point, it is worth saying that polymeric nanofibers are among the best scaffolds for tissue engineering applications, since they reproduce the morphology and structure of the natural ECM, thus providing an ideal setting for cell activities.” (29) The most paying technique to produce polymeric nanofibers is electrospinning. It is a process during which “nanofibers are created from a polymeric solution by means of an electrostatic force.” (29) Another method for creating nanofibers would be electrodynamic printing. (29)

2.2.2. Bone grafts – composite biomaterials

The materials mentioned above are single composites. But it is also worth taking a look at composite biomaterials. They are of big interest, because new scaffolds with improved properties can be constructed. It is possible to imitate natural bone with the help of nano-composites. In addition, deficits of one material can be balanced by combining it with

another one. Examples are the combinations ceramics/metal and collagen/HA. As forementioned, ceramics are biocompatible but show a certain lack in mechanic stability. The combination with metals (as titanium) is more load bearing, and has benefits for the metal as well, because they are known to show little biocompatibility. Collagen/HA composites were the first choice for bone grafting for a long time. Individually, collagen and HA push osteoblast differentiation, whereas in combination they speed up osteogenesis. Polymers/ceramics constitute another good composite. They try to imitate the structure of natural bone ECM. (29, 36)

2.2.3. Imitation of ECM as a chance

In most of the cases the reason for orthopedic implant-failure (prostheses, bone screw, bone graft) is a lack of osteointegration. Not only is this undesirable in the patients interest, but it poses an economic problem as well. This underlines the need for improved orthopedic materials. Key points are osteointegration and the enhancement of bone formation. Osteointegration describes a process during which new bone is built in direct contact with the implant. (37)

Lately, science came up with bioinspired strategies that have the aim to increase implant integration. Bone consists of osteoblasts, osteoclasts and osteocytes. Osteoblasts are of most interest. They differentiate from MSC and osteoprogenitor cells, which can be found in the bone marrow. The environment plays an important role in differentiation. In our case, the environment is the ECM. Science tries to recreate this construct. Speaking in architectural terms, the aim is once again a scaffold. (37)

As a matter of fact, the ECM of every tissue looks different. We want to concentrate on bone. "In bone, the ECM consists of mainly of an organic phase known as osteoid, which constitutes approximately 20% of bone mass, and a mineral phase." (37) Collagen type I makes up the majority of the organic phase. Hydroxyapatite presents most of the mineral phase. Bone ECM has structural and biological functions. It provides mechanical stability but also ensures signaling, such as bone morphogenic protein (BMP). (37)

"Due to the important regulatory role that ECM molecules play on cellular responses *in vivo*, full-length ECM proteins have been studied as potential adhesive scaffolds for bone

defect healing and implant integration.” (37) In vivo, ECM implants occur as crosslinked membranes, gels or sponges. Though they have been successful in some studies, ECM implants were not able to come into every day orthopedic use due to its high costs, low solubility and risk of immunogenicity. ECM-derived adhesive peptides are a favorable alternative. They represent the key sites for adhesion, signaling and spreading, and are much shorter than full length ECM proteins. Therefore they can be manufactured more easily and cost-effective. Among them is a peptide that attracts most interest: BMP. Its main effect is on bone formation and to “regulate key steps in the process of bone morphogenesis, such as mitosis, chemotaxis, cartilage induction, osteoblastic differentiation and bone formation.” (37,38-41) “In particular, BMP-7 appears to be one of the strong osteoinductive molecules that can stimulate new bone formation.” (42)

Alas, most peptides investigated show good results in vitro, but lack clinically relevant animal models.

2.2.4. Stem cells as a promising approach

“Apart from an appropriate scaffold, a successful system for bone tissue engineering also requires the presence of bioactive cells able to regenerate the damaged tissue.” (29) They need to be integrated into the 3D scaffold. Though different cell types can be used, mesenchymal stem cells (MSCs) seem best suited for this job. Stem cells seem ideal because of their abilities of self-renewals and differentiation. They have several advantages: they are multipotent and can be accessed easily, because they can be found in bone marrow, adipose tissue, umbilical cord and dental pulp. Therefore, they can easily be isolated. (29)

Another important aspect that makes MSCs so attractive, is the fact that, not like embryonic stem cells (ESC), they escape ethical concern. “Currently, good manufacturing practice (GMP) has been developed to produce the cells for use in clinic.” (43)

MSCs can be obtained from the superior iliac crest, femur, and tibia, by bone marrow aspiration. Since the osteogenic differentiation potential of MSCs from bone marrow seems to decrease with age, scientists have been looking for other sources. Adipose tissue seemed the ideal resource. An exuberance of adipose tissue exists in the body and

it can easily be obtained by liposuction. Adipose-derived stroma cells (ADSCs) retain their ability to differentiate up until old age. (42)

MSCs are able to differentiate not only in vivo. The molecular pathways have been studied and therefore researchers are able to imitate them in vitro. Furthermore, “MSCs possess immunologically specific characteristics; therefore they would be general donors for therapeutic applications.” (42) Because of their lack of CD80 and CD86, they do not trigger T-cell activation, which means they are not rejected by the immune system. (42)

“One of the most important capabilities of MSCs is their migration capacity in response to signals produced by an injured bone.” (44,45) “At the injury site, MSCs could possibly help with repair in two ways: [1] they differentiate to tissue cells in order to restore lost morphology as well as function, and [2] MSCs secrete a wide spectrum of bioactive factors that help to create a repair environment.” (42) Chemotactic cytokines (chemokines) concentration seems to have an influence on the migration of the cells. (42)

Not only are MSCs useful in building scaffolds that mimic natural bone, they could also be used as carriers for therapeutic genes. If they could release growth factors and cytokines they would be able to enhance new bone formation in areas where bones have suffered big damage. The genetic manipulation is done by transduction or transfection. Transfecting MSCs with BMP has been of highest interest. However, the short half-life of recombinant growth factors limits these approaches. (42)

Though we know about a lot of preclinical studies, we lack animal studies, which could prove the success of MSCs. Recently, studies have shown that MSCs that have been modified to produce osteogenic or angiogenic growth factors show even better results. In these studies, MSCs have been programmed to produce growth factors to promote the repair and regeneration of bone. This way, bone healing can be improved dramatically. Though studies investigate MSCs that produced osteogenic and angiogenic growth factors respectively, best results have been shown when both factors were combined. Thereby bone and blood vessel formation could be stimulated simultaneously. Please note, that it were preclinical studies only. (32)

Via this approach, researchers came up with the idea that it may not only be MSCs that are capable of advancing bone formation, but that angiogenesis plays an important role as well. The synergism in MSCs and endothelial progenitor cells (EPCs) seems promising. In addition, the idea of MSCs differentiating into osteoblasts and thereby forming new bone

as their only purpose has been outrun. “Investigation has suggested that stem cell therapy may exert its effects on bone healing by a variety of other ways including the secretion of growth factors which attract other bone forming cells or vasculature, anti-apoptotic effects, and immune modulation.” (32) Nevertheless, further clinical investigation is needed. (32)

2.3. Bone putty

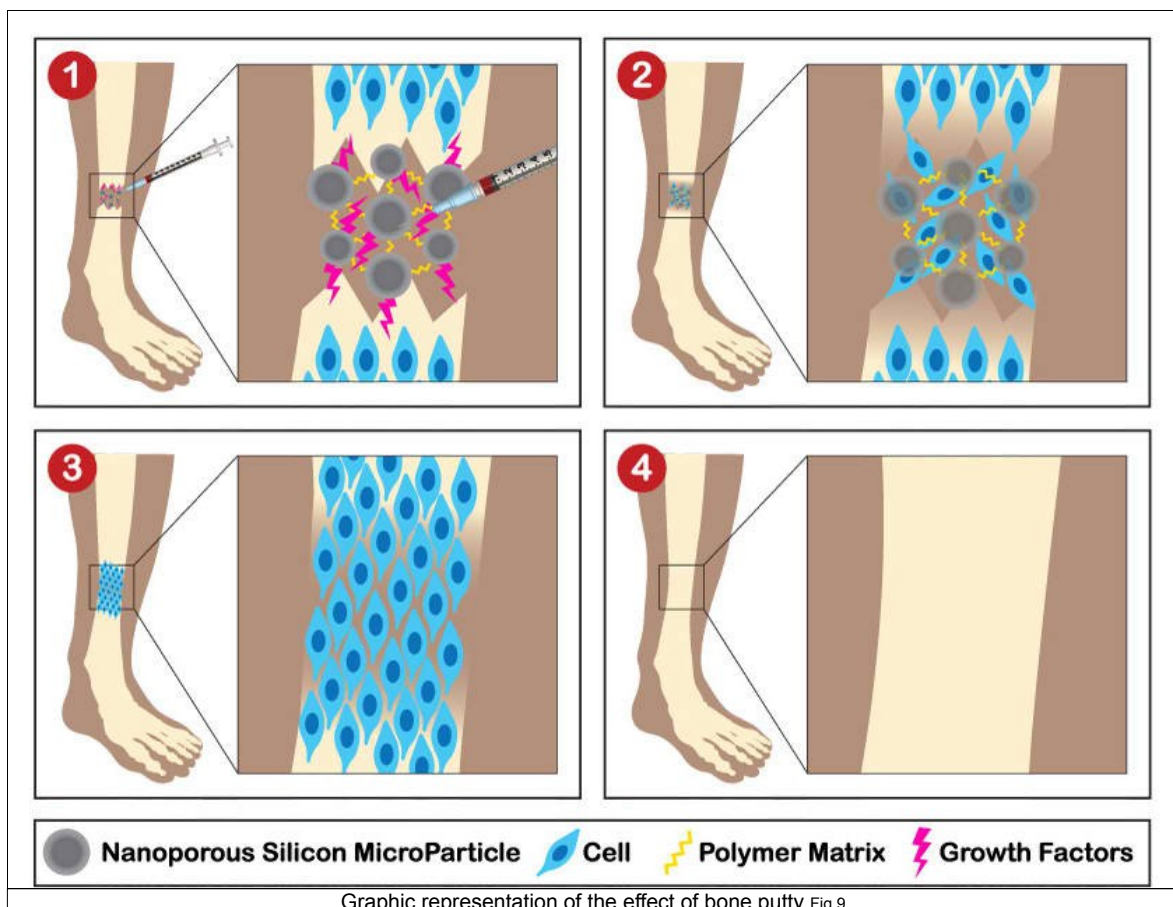
Another subject worth investigating is the healing of complex fractures. Especially for American researchers it seems to be interesting. The main idea evolved, so to say, on the battlefield.

Soldiers suffer, in contrast to civilians, from massive wounds and complicated fractures. (46) Thanks to the progress in body armor and medical fields, most soldiers survive these traumatic injuries. However, science still looks for strategies to speed up bone healing and minimize the necessity of orthopedic surgeries. “UC Davis biomedical engineer Kent Leach has received a Congressionally Directed Medical Research Programs (CDMRP) Hypothesis Development Award from the U.S. Army to explore a new approach to tissue regeneration that may speed bone healing and return to function. The results of the study will help develop an effective treatment for wounded soldiers or veterans struggling with slow- or non-healing bone defects.” (46) Dr Leach made use of stem cells (SCs). SCs from adipose tissue, to be exact. He appreciates their advantages, which are, as mentioned above, the cumulative existence in the human body and the easy way of harvesting them. With the help of these ADSC Dr Leach is able to stimulate the formation of microvascular networks. As explained above, the formation of blood vessels is vital for developing bone. Blood vessels provide the new cells with oxygen (O₂) and nutrients. In a special procedure Scs are integrated into a gel, which then can be directly put on the wound. It is called composite hydrogel. A combination of polymers allow the hydrogel to stay in place as long as needed and then degrade gradually.(46) This method is superior to the more common use of SC injections. More SCs stay at the damaged site and thereby speed up bone healing and neovascularization. Next will be a combination with chemicals, which will attract the patients own bone-building substances. The big advantage is that no drugs have to be taken orally. (46)

“We’re drawing native tissue repair elements directly to the bone defect,” says Leach. He envisions a scenario where surgeons in the operating room extract fat, process it in a

machine that separates out the stem cells, mix the cells into the composite hydrogel, and then inject the mixture directly into a fracture.” (46) Figure 9 illustrates the effect of bone putty on a complex fracture.

Needless to say, science-fiction authors came up with ideas for bone healing. They even were obliged to, considering the super heroes they create and battles they let them fight it. In Clifford Simak's *Time is the Simplest Thing* (1962) we come across full body healing, by using alien medical technology, called gobathian (47)



“The doctor reached the door. He stooped with his stethoscope placed against the mummy, then stepped back from the bed.

"He's dead," said Blaine. "His breathing stopped and it was a longtime --"

"Yes, he's dead. He never had a chance. Even with gobathian he didn't have a chance."

"Gobathian? That was what you used? That was why he was all wrapped up?"

"He was broken," said the doctor. "Like a toy someone had thrown on the floor and stepped on. What do you know about gobathian?" he asked.

"I've heard of it," said Blaine.

"An alien drug," the doctor said. "Used by an insect race. A warring insect race. And it's done miracles. It can patch up a smashed and broken body. It can repair bones and organs. It can grow new tissue." (48)

The idea proved to be so fantastic that it even found way into kid's rooms. In Joanne K. Rowling's *Harry Potter and the Chamber of Secrets* Harry gets all the bones of his arm removed by a clumsy teacher.

"What he saw nearly made him pass out again.

Poking out of the end of his robes was what looked like a thick, flesh-colored rubber glove. He tried to move his fingers. Nothing happened.

Lockhard hadn't mended Harry's bones. He had removed them."

[...]

"Madam Pomfrey was holding a large bottle of something labeled *Skele-Gro*. "You're in for a rough night", she said pouring out a steaming beakerful and handing it to him.

"Regrowing bones is nasty business."

So was taking Skele-Gro." (49)

In 2009, the Defense Advanced Research Project Agency (DARPA) funded a study on what they call *fracture putty*. This is indeed a putty-like material for the regeneration of complex fractures. (50)

The name of the project is "BioNanoScaffolds for Post-Traumatic OsteoRegeneration." (51)

With the help of the putty they want to spare soldiers from amputation and make them fully operational in a short space of time. Similarities to Dr Leach's idea is the ability of the putty to degrade once it is not necessary any more. Principal researcher Mauro Ferrari states: "At the same time, the putty will facilitate the formation of natural bone and self-healing in the surrounding soft tissue through the attraction of the patient's own stem cells. The putty will have the texture of modeling clay so that it can be molded in any shape in order to be used in many different surgical applications, including the reconnection of separated bones

and the replacement of missing bones." (50)

The goal of the program is to unite materials science, mechanics, and orthopedics. (50)

The putty is applied in and around shattered bone of non-joint injuries. This way, it offers a structure, that resembles the original bone, which makes the regeneration of it a lot easier.

In addition, the fracture is sturdy. (51)

Ferrari further says "The fracture putty will serve as a bioactive scaffold and will be able to substitute for the damaged bone." (52)

2.4. 3D bone printer

But what shall be done if the damage to the bone is too big? When reconstruction is impossible. It would be convenient to be able to regrow bone. Or replicate it. Replicate it really fast. Like printers possess the ability to multiply hundreds of papers in minutes. In effect, scientists developed a technology that uses ordinary printers to reconstruct bone. They build them three dimensionally (3D). We have come across similar things in *Cantata 140* (1964) by Philip K. Dick (screen adaptation *Repo Man* (2010)) or *The Fifth Element* (1997) by Luc Besson. The Fifth Element is part of a weapon able to save the world from the Great Evil. When the Mondoshawans, an alien race, want to return to the planet earth as to help the human race, they get attacked and the only piece of the Fifth Element remaining is a hand. But as the story takes place in the 23rd century, technology has evolved. Modern machines are able to reconstruct the Fifth Element layer by layer, the final product being a humanoid woman called Leeloo. (53)

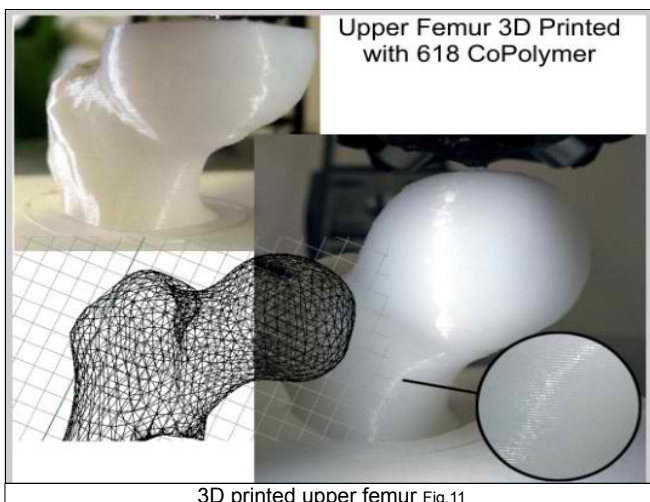


Nevertheless, the idea was born a lot earlier. In Philip K. Dick's 1964 novel *Cantata 140* *artiforgs* are mentioned. These are artificial organs that can be created mechanically. The idea was so popular that it was adapted in Miguel Sapochnik's *Repo Men* (2010). The corporation *The Union* has recognized the growing need for organ transplants. Part of an advertisement for these transplants is shown in Figure 10. Note, that the spine is upside down. Due to the horrendous prices most people cannot afford them and purchase them on credit. The problem is: if you cannot pay within 90 days, *The Union* wants the organ

back. By any means...

Is this possible in reality? In 2012, Dutch researchers have proven: it is! "A 3D printer-created lower jaw has been fitted to an 83-year-old woman's face in what doctors say is the first operation of its kind." (54) The patient suffered from a chronic bone infection. Because of her age, which carries a lot of risk factors with it, surgeons abandoned reconstructive surgery and sought new approaches. Ruben Wauthle was head leader of the team. Research was "carried out at the Biomedical Research Institute at Hasselt University in Belgium, and the implant was built by LayerWise - a specialized metal-parts manufacturer based in the same country." (54)

The whole implant is made of titanium. It was not created en bloc, but layer by layer. To achieve this, titanium powder was used, which was heated and then composed by laser. Though the lower jaw is a rather difficult bone, it was finished within hours. The pattern came from a CAD (computer aided design) image.(54) A laser beam was used to melt the titanium particles. Then layer by layer was fused together. "It took 33 layers to build 1mm of height, so you can imagine there were many thousand layers necessary to build this jawbone", (54) says Ruben Wauthle. "Once completed, the part was given a bioceramic coating." (54)



The actual surgery time, during which the transplant was attached to the woman's face, was 4 hours. For comparison: normal reconstructive surgery time would have been twenty hours. Other benefits are the weight (only one third heavier than the woman's own jaw), the lower costs and the decrease in hospitalization time. "Shortly after waking up from the anesthetics the patient spoke a few words, and the day after the patient was able to swallow again," said

Dr Jules Poukens from Hasselt University, who led the surgical team." (54) In the meantime, the corporation also offers costum-made upper femur prostheses, which can be seen in Figure 11.

Other projects try to create a substance to integrate into damaged bone. There, new cells

can use it as a scaffold. The goal is to build a lowload bearing construct that is able to dissolve when it is not needed any more and allow new bone to form over it. A suitable material has been found when zinc and silica was added to ceramic powder (calcium phosphate). This way strength was doubled. (55)

“To create the scaffold shapes [...] a printer which had originally been designed to make three-dimensional metal objects” (55) was being used. Plastic binder served to combine the single layers. This process is repeated until the scaffold is finished. It is then baked for two hours at 1250° Celsius (55). In vitro studies show that immature fetal bone cells start to grow over the construct within the first week.

What would be the next step? Replacing the whole skeleton? Or modifying it. In *The Last Legionary* a novel series by Douglas Hill Keill Randor, the main character, has to get his skeleton replaced due to a lethal dose of radiation. Unfortunately (or luckily) modern medicine can only dream of such procedures. That leaves us with modifying, represented by a special race, the *Na’vi*. They live on the planet Pandora and appear in the movie *Avatar* (2009) by James Cameron. Though they are a humanoid race they are much taller than humans. Their skin is of blue color and they have a tail. The focus is on their carbon reinforced bones. Modern medicine is not yet able to increase bone density with the help of carbon, but nothing has been left undone to help patients with osteoporosis. Note: even a metal is used, though in its ionized form. Calcium and vitamin D have been the foundation of an effective therapy.



2.5. Skeleton tuning

Despite all these advances in bone healing and reconstruction, the alternative would be prevention. At the Donau University Krems (Austria) approaches have been made to cultivate ligaments and meniscal material to prevent knee replacement. There are some striking parallels to bone putty mentioned above. In this case, it has been the incorporation *Arthro Kinetics* that fueled research. Their fundamental idea is to cure rather than replace.

They invented the Cartilage Regeneration System (CaReS), which “is a novel matrix-associated autologous chondrocyte implantation (ACI) technique for the treatment of chondral and osteochondral lesions.” (56) The implantations of CaReS took place in different clinical centers and the International Knee Documentation Committee (IKDC) score was used to show the improvement after therapy. A prospective study over five years has been made. After an average of thirty months IKDC scores improved significantly and global pain decreased. (56)

Though ACI has been used over decades, it requires two surgical interventions. First, a cartilage biopsy is needed to acquire samples for cell culturing. Second, a periosteal flap is creating which serves as a holder for the cultivated chondrocytes. This flap is thought to be a mechanical protection for the cells. And indeed, this technique is prior to others (as debridement, mosaic plasty or osteochondral cylinder transplantation) and shows a good clinical outcome. Nevertheless, the creation of a periosteal flap brings along risks. This is why matrix-associated procedures of ACI have been developed. (56)

The osteochondral and chondral defects have been due to trauma, degeneration or osteochondritis dissecans (OCD). Radiological images and magnetic resonance images served to rate success. (56)

Before the actual surgery could take place, patients had to go through arthroscopic procedure to determine location and size of the defect. Adjacent cartilage, menisci and ligaments were evaluated as well. Chondrocytes, drawn from a biopsy specimen, were then isolated and cultivated. “During the [...] cultivation of the CaReS implant for 10 to 12 days in autologous serum, the risk of dedifferentiation [...] is minimized.” (56) A special manufacturing process ensures homogenous cell distribution in the implant. Additionally, it makes the implant stable enough for surgical handling. (56) Figure 12 illustrates the steps of the CaReS system.

Via arthrotomy the defect site was found and debrided down to the subchondral bone. “The base of the cartilage defect was coated with fibrin glue [...] before the implant was transferred [...]” (56) *Arthro Kinetics* uses a three dimensional hydrogel based on collagen type I. The implants can be manufactured individually and adapted in size and height. (56) “For isolated femoral and tibial defects, the knee joint was immobilized for 48 hours in a brace [...]” (56) Advice has been given for physical training after six weeks and training for enhanced muscle formation after twelve weeks. 80% of patients and doctors agree that

the outcome has been either very good or good. (56)

“One can speculate that because of the opening of bone marrow spaces and blood vessels during debridement of the subchondral bone in OCD defects, chondroprogenitor cells gain access to the defect site and migrate into the hydrogel and therefore contribute to the cartilage specific extracellular matrix production, resulting in better cartilage regeneration”. (56) The conclusion of the study is that the outcome of this new technique resembles the outcome of conventional ACI. (56)

3. Prosthetics and robotics

The following chapter will outline the advances in prosthetic technology, not only focusing on artificial limbs but also on the progress in the field of rehabilitation. At first, it is going to give a short insight in the improvement of leg prostheses, emphasizing on the headway of running and sprinting technologies. Next, it will concentrate on artificial hands and the progress made in control. The chapter will end with an overview on exoskeletons and the services they accomplish not only in activities of daily living but also in the rehabilitation of stroke patients. A prospect on means of biomechanical energy harvesting will be given.

Though the fusion of robotics and mankind is a vision of science fiction, the need for prosthetics dates back to ancient times. Therefore it is worth taking a look at the development of prosthetics through the course of time.

3.1. A brief history of prosthetics



Prosthetic toe (1500 B.C.) Fig.13

The need for replacement for missing limbs dates back to ancient times. In the year 2000, researchers in Cairo, Egypt, unearthed what they believe to be the oldest documented artificial body part -- a prosthetic toe made of wood and leather, shown in Figure 13. Back then artificial limbs were made out of very basic materials, like wood and metal.

Leather straps were used to attach the devices to the body. (57)

The first record of a prosthetic replacement can be found in the book of Vedas, in Rig-Veda to be precise. This book is written in Sanskrit and thought to be compiled around 3500 B.C. It tells the story of Queen Vishpla, who lost a leg in battle. It was replaced by an iron leg, which empowered Queen Vishpla to return to combat. (57)

The Greeks and Romans also made contributions to the development of prosthetic limbs. A record of Herodotus (500 B.C.) tells of a prisoner, who cut off his foot in order to escape the chains and got his foot replaced by a wooden leg. (57) In 1858 an artificial limb made of copper and wood was found in Capri, Italy. Archaeologists say it dates back as far as 300 B.C. (57)

There is record of a Roman general, called Marcus Sergius, who lost his right hand during the second Punic War (218 B.C. - 201 B.C.). His replacement was made of iron. With it, he was able to hold his shield and thus return to the battle. (57)

“A description of Marcus Sergius is found in the seventh book of Pliny's Natural History, published in AD 77:

Nobody - at least in my opinion - can rightly rank any man above Marcus Sergius, although his great-grandson Catiline shames his name. In his second campaign Sergius lost his right hand. [...]

He had a right hand made of iron for him and, going into battle with this bound to his arm, raised the siege of Cremona, [...]. What piles of wreaths he would have amassed in the face of a different enemy!” (58)

With the Dark Ages came an era during which the progress in firearms multiplied the number of amputations and therefore the need for prosthetic devices. Though simple devices made of wood and metal were still common, more complex prostheses evolved. (57) During the Romantic and late Romanic period the French surgeon Ambroise Paré (1810 - 1890) impelled the development of prosthetics limbs. (57)

At the end of the 17th century a Dutch surgeon, Pieter Verduyn, developed a lower leg prosthesis that is similar to today's thigh-corset prosthesis. It consisted of external hinges and an improved leather cuff to attach to the body. (57) Note, that the contributions of Paré and Verduyn still play an important role in modern day prosthetics.

The start of the Civil Wars encouraged research in the fields of prosthetics. The huge numbers of wounded and amputees during World War I and II induced great dedication amongst surgeons, orthopedists and engineers. 1946 was an important year for advances

in lower limb replacements. Improvement of materials, technologies and surgical techniques has ever since to advances in prosthetics. Today, electric arms can be moved using batteries, and myoelectric prostheses use electric impulses that can even make the patient feel his/her surrounding. The possibility to endow prosthetic legs with toes and match the covering with skin tone and hair pattern was a big step forwards in aesthetics.

Once the mark of a villain, like Captain Hook in the nursery story *Peter Pan*, artificial limbs nowadays appear in a lot of science fiction stories, often worn by the good guys. The idea of humans fusing with technology fascinates mankind. We could turn ourselves indestructible.

3.2. Running on artificial legs

A different source tell us the story of Cosmas and Damian. Chronicles tell us that the twin brothers, born in Arabia, operated around 200-300 at Aegea (nowadays Ayas, Turkey (59)). The famous altarpiece in Figure 14 depicts the brethren.

They lived in complete abstinence and by studying medicine they tried to relieve the sufferings of their friends and neighbors. Their efforts were honored by God, and they became the most brilliant physicians the world had ever seen. (60)

They helped the rich and the poor, even animals, refusing all payment. Under Diocletian and Maximian they were thrown into prison. The next day, they should have been burnt, but while the brothers prayed, the fire lost its power. The executor suspected them of being magicians and questioned them again. But as Cosmas and Damian stayed calm, the executor became more furious and ordered to stretch the brothers and pelt them with stones. Even the stones were not able to harm the siblings. The governor ordered to attack them with arrows. But instead of the brothers, those who



Cosmas and Damian Fig.14

fired the arrows were wounded. In the end, the governor commanded to kill Cosmas and Damian by sword. They died on September 27th, remaining their Patrons Day (60)

Most famous and depicted many times is the story of a dream. A man, suffering from cancer of the leg, traveled to Rome to pray. He fell asleep in the church and dreamed of Cosmas and Damian. They were standing beside him, one carrying a box of ointment, the other holding a knife.

“And he who bore the ointment said, “What shall we do to replace this diseased leg when we have cut it off?” and the other replied, “There is a Moor buried just now in San Pietro in Vincole, let us take his leg.” Then the brought the leg of the dead man and with it they replaced the leg of the sick man, who became whole, being anointed with the celestial ointment.” (60)

When the sick man woke up, he noticed that he had been healed indeed.

In modern times, the idea of man and technics fusing, thereby enhancing human capabilities, has become popular. The correct term for such a hybrid would be *cyborg*, or cybernetic organism. Manfred Clynes and Nathan S. Kline coined the term in an article published in 1960, in which they wrote about the advantages of self-regulating human-machine systems in outer space.(61)

In the 1970s one of the most famous cyborgs was being introduced in the television series *The Six Million Dollar Man*. The adventures of the bionic man are refer to the novel *Cyborg* (1972) by Martin Caidin. (62)

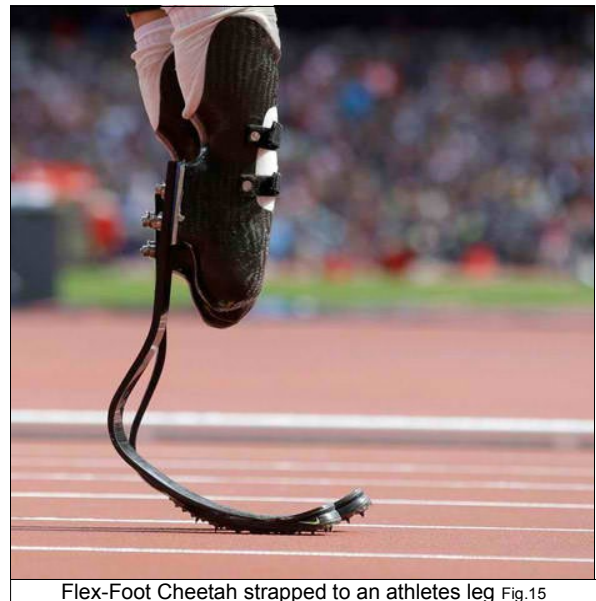
The series tell the story of Steve Austin, a former astronaut, who had crash and was severely injured. The title of the series comes from an operation he undergoes and during which he is rebuild. His right arm, left eye and both legs are replaced. In the opening sequence quotes,

“Steve Austin, astronaut. A man barely alive. Gentlemen, we can rebuild him. We have the technology. We have the capability to build the world's first bionic man. Steve Austin will be that man. Better than he was before. Better, stronger, faster.” (63)

But the idea of enhancing human life by technology and the enourmos progress of science brought up a couple of new questions. How far was science allowed to go, intefering with

human life? Would all the technological progress one day turn against its creator? Will the frontiers between human and artificial life become blurred? How to define *humanity*?

In 1982 Ridley Scott creates an outstanding science fiction film, that does not only provide spectators with futuristic ideas but examines the questions mentioned above as well. *Blade Runner* takes place in 2019 and is the story of a retired police officer, Rick Deckard, who is called back into duty. His job as a Blade Runner is to hunt and track down bioengineered creatures, known as replicants, and destroy them. Though replicants these days look a lot like humans, the problem of distinction can be overcome using the Voight-Kampff test. This is a



Flex-Foot Cheetah strapped to an athletes leg Fig.15

set of questions plus a machine evaluating bodily functions and empathic response – briefly speaking a very advanced lie detector. In this case, Rachael represents a very special kind of replicant: her creator was able to extract memories of a real person and implant them, so she would pass the interrogation. In the course of his commission Deckard and Rachael fall in love and are able to leave to an uncertain future. (64)

In recent years, the expression *Blade Runner* had been used in another context. In the Summer Olympic Games 2012 in London, Oscar Pistorius “became the first double leg amputee to participate in the Olympics when he entered the men's 400 metres race and was part of South Africa's 4 x 400metres relay team. He also took part in the 2012 Summer Paralympics.” (65) His prosthetics, the so called *Flex-Foot Cheetah*, shown in Figure 15, brought on his nickname *Blade Runner* or *The Fastest man on no legs*.

The following paragraphs will take a look at *Flex-Foot Cheetah* (made by Össur) and the biomechanics of sprinting in transtibial amputees.

“The *Flex-Foot Cheetah* blade is a custom-built, high performance carbon fiber foot designed primarily for sporting activities.” (66) It can be used by transtibial and transfemoral amputees, being attached to the posterior socket. As its name giver – the cheetah being the fastest land animal with top speeds of 112 – 120km/h (67) – the *Flex-*

Foot Cheetah provides comfort and power for its bearer by imitating the hind legs of a cheetah. It can carry a weight up to 147kg, although weighing little over 500g itself. (66)

The special shape of the prosthesis tries to imitate the natural function of the foot/ankle joint. Sideways it looks like a J. (66)

Normally, epoxy is used for the fabrication of these kind of prosthesis. In the case of the *Flex-Foot Cheetah* other polymers can be considered as well, depending on the application. (66) 30 to 60 small sheets of material are needed to build the final blade. The material gets cut into squares and is then pressed together. This way, the emergence of bubbles is minimized. This is desirable because bubbles could cause breaks. After cooling down, the sheets can be cut into shape. (66)

The design, being accomplished in 1997, has not changed much. It is a J-shaped carbon composite. This allows the user to store and release the energy, that gets build up while running. (66) It works like a spring. "When a user is running, the prosthesis' "J" curve is compressed at impact, storing energy and absorbing high levels of stress that would otherwise be absorbed by the runner's ankle, knee, hip, and lower back. At the end of stance phase, the *J curve* returns back to its original shape, releasing the stored energy and propelling the user forward." (66)

Another feature of the *Flex-Foot Cheetah* is the fact, that the carbon layers are thicker where the impact while running is higher, whereas less carbon is found in areas where flexibility is needed. Due to the J-shape, the *Flex-Foot Cheetah* has no heel. This way, the stance and swing face of an able-bodied runner are mimied. (66)

At the prosthesis toe the spike plate of a sprinting shoe or the sole of an athletic shoe can be attached to optimize traction. Recently, the company *Össur* has developed some modifications of the *Flex-Foot Cheetah*. The *Cheetah Xtreme* with Nike Spike Pad has been "designed specifically for fast, short-distance sprints (100-200m), the carbon blade features a more extreme curve. This dynamic shape allows the foot to flex more and, as a result, offers a powerful energy kick. A longer, flatter toe enhances push off, while the attachment pylon (plantar-flexed at seven degrees) supports better forward progression. (66)

The *Cheetah Xtend* with Nike Spike Pad has been designed with constructive criticism and feedback of Oscar Pistorius. Being more curved in the toe area, it allows the user to rollover smoothly and thereby providing the perfect choice for longer sprints and short

distance running. Push off and forward progression are enhanced as well. (66)

Studies have proven, that there is a noticeable difference between the biomechanics of running and sprinting.(68) What are the differences in amputees and what adaptations do they have to make?

“Are modern running prostheses now equal or perhaps superior to biological limbs?” (69)

3.3. Biomechanical adaptations and sprint kinematics in lower limb amputees

The successes of Oscar Pistorius, a bilateral transtibial amputee, have triggered controversy regarding the function provided by artificial limbs. Functional, physiological and mechanical properties were investigated. The study of Weyand et al. (69) demonstrates similarities as well as dissimilarities in sprinting in amputees (bilateral) and able-bodied athletes respectively. Based on the hypothesis, that amputees should have a lower metabolic cost while sprinting because of lacking lower-limb musculature, they started their first tests. Amputees and intact-limb male athletes were compared. (69)

Oxygen uptake was investigated. On a treadmill, participants had to do 5 to 7 minutes running intervals, with 3 to 5 minutes rest periods alternating. The expired air was compiled through a pneumotach into a mixing chamber. The results were diverse. Though the amputee's subjects metabolic costs were only slightly lower while running longer distances, the metabolic cost decreased drastically in 400 m sprints. (69)

The conclusion is that the “amputee's metabolic cost of running is similar to that of intact-limb elite and subelite distance runners and lower than that of intact-limb male sprinters.” (69)

Secondly, sprinting speeds were examined. On a treadmill the top speeds of each participant were determined. It resulted that the sprinting endurance of amputees and intact-limb runners is identical. (69) Note, that the sprinting speeds of the amputee “decreased in relation to trial duration in the same manner as the speeds of intact-limb runners did.” (69)

These results could be accomplished by excluding start and acceleration portions. Subjects lowered themselves from the handrails onto the treadmill when the desired top

speed was attained. Otherwise, relatively poor starts would be expected for amputees, who lack “ankles, ankle extensor muscles, and feet to transmit muscular force and power distally during the push-off phase of each accelerating step.” (69)

The third hypothesis scrutinized sprinting mechanics with the help of videotaping. In this case most striking differences were found. Results were closely related to speed, though. The greatest difference was observed in fast speeds. (69) “Although the top speed results attained by [the] amputee and intact-limb subjects were similar, their aerial times, swing times, and weight-specific ground reaction forces were all markedly dissimilar.” (69)

Swing and aerial times were shorter in the amputee. Along with longer ground contact, this contributes to the fact that the amputee subject could be as fast as the able-bodied athletes. In physiological terms, lower limb amputee- athletes with modern prostheses and able-bodied athletes are very similar, though they differ in the mechanics of running. (60)

Other studies with unilateral, transtibial amputees have outlined the biomechanical adaptations needed when running with a prosthesis. In sprinting, special prostheses made of carbon fibre are used. They have a flexible thigh/foot component, which will deform while loading and recoil at toe-off. (70)

An up-on-the-toes gait, typical for sprinting, can be achieved. The disadvantage of this study is the fact, that only two subjects, both unilateral amputees, were examined. Prosthetic and sound limb respectively were matched. (70)

“Results indicate that the joint moments and muscle power outputs on the prosthetic limb were different to those determined for the sound side.” (70)

3.4. *Bionic leg prostheses*

In everyday life people with artificial lower limbs want to maintain a natural way of walking. In former times, a man with a wooden leg was unmasked by hobbling. Nowadays, modern prostheses enable hampered people to walk naturally. This could be achieved with the help of bionic prostheses. Bionics tries to apply biological methods and systems found in

nature to modern technologies and engineering. When in the 1970s the television series *The Six Million Dollar Man* became popular, so did the science of bionics.

This chapter will present different bionic prostheses: *Genium*TM by Ottobocks and a bionic ankle-foot prosthesis.

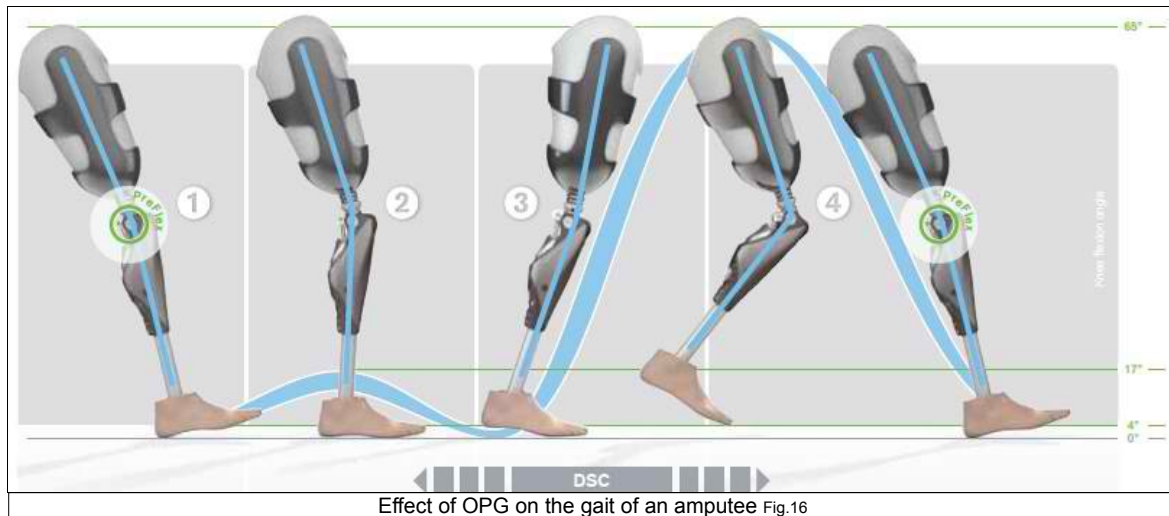
Thorough research and 14 years of practical experience with a system called *C-Leg*[®] led to the development of the *Genium*TM Bionic Prosthetic System. Its purpose is to favor the musculoskeletal system while enabling an intuitive utilization without conscious control. (71)

The *Genium*TM is a hydraulic, monaxial joint which is steered via different sensors using nine different signals. It has different modes that can be used, adjusted to the requirements of the amputee. Most impressive is the new technology of the Optimized Physiological Gait (OPG). It can be cut down into four phases, the graphic equivalent can be found in Figure 16:

- PreFlex(4): Before touching the ground, the angle in the knee is adjusted to 4°. This makes it possible to reach full ground contact more quickly.
- Adaptive Yielding Control(1): While walking, the maximum angle in the knee is restricted to 17°, which gives users more control and allows natural walking in planes and slopes.
- Dynamic Stability Control(2): A gyroscope and a two-axis accelerometer generate information about the environment the user walks in. Two different ways of resistance and realising can be chosen, depending on the ascent.
- Adaptive Swing Phase Control(3): Lower leg pendulum can be controlled dependent on the clothes and footwear of the user. (71)

In combination, OPG helps to accomplish a physiological gait while reducing the exertion of force and cognitive demands. In addition, *Genium*TM is equipped with the possibility of using *My Modes*. These can be activated via remote control or tapping. Additional movement patterns can trigger different functions. There are different modes for managing stairs safely, standing, and sitting. The remote control serves as step counter, but gives information about battery and the need of check-up. For users with defective hearing it is possible to install an audible signal. *Genium*TM is splash-proof and can carry a load up to

150kg. (71)



The problem of different walking velocities occupies a lot of engineers. People with a leg amputation usually prefer to walk slower, because it takes more metabolic energy to walk at the same pace as able-bodied people. In order to assimilate metabolic cost, engineers have developed a prosthesis that mimics an ankle while walking. (72)

In able-bodied people most energy during walking comes from the calf musculature. “While using commercially available passive-elastic prostheses, people with a leg amputation (PWA) require 10–30% more metabolic energy to walk at the same velocities as non-amputees:” (73-75) This is because energy can only be stored and released by passive-elastic prostheses while in contact with the ground. PWA get tired more rapidly.

In the study, Herr and Grabowski (72) examine a new designed bionic ankle-foot prosthesis. It is able to do positive and negative work via a series-elastic actuator. (72)

It creates a push-off force and performs net positive work by using a battery. Then, amputees using the bionic ankle-foot prosthesis and others using a passive-elastic prosthesis were compared. It was indicated, that amputees equipped with the bionic prosthesis were walking at the same velocity as able-bodied people. (72)

Unfortunately, the metabolic cost could not be decreased below normative levels, which would have been the goal. “Factors that could contribute to metabolic normalization but not augmentation in PWA using the bionic prosthesis may include limited energy transfer between the bionic prosthesis and the proximal leg owing to the lack of a rigid interface connecting the residual limb to the socket, the lack of a working gastrocnemius muscle in

the residual limb of PWA, and compromised walking stability.” (72)

In the future, scientists work on building a bionic devices that allows amputees to decrease metabolic energy even below standards of non-amputees. (72)

3.5. Can I give you a hand?

Though the number of lower limb amputations seems to surmount the number of upper limb amputations (more than 70% of foot and leg amputations being related to Diabetes mellitus, according to the International Diabetes Federation (IDF)), the replacement of arms and hands offers a wide subject of speculations in science fiction. But since the days of Captain Hook in *Peter Pan*, ideas and plans for human hand replacement have come a long way, all the same in fiction and science.

Amputation has been a common procedure ever since. It was an easy way to get rid of deformations and severe injuries. But unfortunately, in its early stages it was a death sentence. Nevertheless, inventors searched for a way to replace the arm, being an important tool in everyday life and war.

One of the most significant achievements is the iron hand of Götz von Berlichingen (1480 – 1562), who is depicted in Figure 17 on the left. During a besiegement he lost his right arm in a cannon blast. Nowadays we would describe in as a horrible piece of smithery, but at that times it was a masterpiece. Not only did it allow Götz von Berlichingen to return to



The iron hand of Goetz von Berlichingen Fig.17

battle, but it was a milestone in mechanics as well. It had articulated joints, that could be controlled by gears inside the prosthetic. Shown in Figure 17 on the right. (47)

Since the hand is a complex building, being a composite tissue with an enormous number of joints and different degrees of motion, the best option would be to replace an amputated

hand with an allograft. This path had its beginnings in the twentieth century. The first documented attempt of a hand transplantation was in 1964, in Ecuador. Due to the lack of knowledge in immunosuppressives, the hand was rejected within two weeks. (76)

Advances in immunosuppressive drugs led to another attempt in 1998, in Lyon (France). Jean-Michel Dubernard and his team was able to transplant the right forearm of a brain-dead to 48 year old Clint Hallam, who suffered a traumatic mid-forearm amputation. (77)

The operation lasted 13 hours. Unfortunately, “the patient was not able to adapt psychologically” (78) which led to the amputation of the graft two years later.

Currently, the long term graft survival is 94%, with the help of immunosuppressives. The goal would be “to achieve graft tolerance, which would negate the need for immunosuppression.” (79) *Chimerism* is the key.

3.6. Regrowing body parts

Another way to come around the problem would be to rear bodyparts. Or let them regrow, like in starfish and lizards. To some extent this is already possible.

In science fiction, Frank Herbert wrote about the so called axolotl tank, in which organic material can be regenerated and even reshaped (*Dune Messiah* (1969)). A more famous example for regrowing bodyparts is *Dr Who* (TV series 1963 – 1989). Shortly before the Ninth Doctor turned into his tenth reincarnation, he lost his hand. But it was



The hand of the tenth doctor in a jar Fig. 18

reattached to the Tenth Doctor. Later, he lost it during battle but because of his ability to regenerate for a certain time, he regrew a new hand. The cut-off hand was later found by his companion, who preserved it in a jar and used it to detect the Doctor through time. Figure 18 shows a screenshot of the preserved hand. This is a really interesting aspect and a desirable solution for scientists in real life.

“Regenerative medicine is an emerging interdisciplinary field of research and clinical application focusing on the repair, replacement and regeneration of cells, tissues or organs

to restore impaired function because of congenital defects, disease, trauma and ageing.” (80) Integrating biologically competent cells and engineered tissues can be an elegant way to overcome the problem of donor-shortage.

One would think that our skin is an organ we can never run out of. There are methods of using the patients own skin to cover wounds indeed. This can happen either by skin transplants or harvesting cells and regrowing them on a culture medium. But researchers look for a more efficient way to acquire skin. Skin substitutes are a more convenient way for the patient. These are biomaterials that can function as temporary wound cover or as permanent dermal replacement. Additionally, “they can be used as stimulating agents for cell proliferation and angiogenesis.” (80) Scientists make use of natural (e.g. polypeptides, hyaluron, fibronectin, collagen) as well as synthetic (e.g. polyglycolide, polylactide, polyurethane) materials. But also cadaver skin can be used as a scaffold. These scaffolds usually have growth factors and cytokines integrated to multiply their impact. (80)

“Cell-based therapies with adult stem cells, ES [embryonic stem] cells or reprogrammed somatic cells, respectively, are attractive, particularly if used in autologous transplantation regimens, as inherent problems with rejections of the transplant do not exist, and ethical and moral objections are avoided.” (80)

In recent studies, epidermal stem cells have proven to be a promising source of multipotent stem cells for tissue-replacement. There are two different subpopulations of epidermal stem cells: a basal keratinocyte population and stem cells from the bulge region of the hair follicle. Whereas basal keratinocytes, which can be found in the interfollicular epithelium, can be used in burn patients (isolated from skin biopsy and cultivated on feeder layer), stem cells from the bulge region of the hair follicle can be reprogrammed to grow into neurons, glia cells, keratinocytes, smooth muscle cells and melanocytes. Although this property sounds promising, the identification of the different stem cell population poses a problem. (80)

Despite the progress in skin substitutes, they “are yet not fully functional as they lack differentiated structures as nerves, sweat glands, pilosebaceous structure and blood supply.” (80) The goal is to create tissue engineered skin that has the same morphological and functional characteristics as natural skin. (80)

And even after that there is an obstacle that has to be overcome: scars. Usually actors in

science fiction stories heal without scars. In real life we have to face these unpleasant marks of scarring. They are not only unattractive but sometimes are unhandy when it comes to movement. On top of researchers interest were once more stem cells, in this case to be more precise, fetal skin cells. In utero, fetal skin shows scarless tissue repair. It seems that an unique ratio of transforming growth factor beta (TGF beta) is at the bottom of this remarkable ability. (81)

We find the ability of scarless healing in an even more impressive form in lizards and axolotl. In 2009 Susan Bryant, one of the leading researchers in regeneration and pattern formation, gave an interview in which she states, that fibroblasts play a crucial role in patterning. (82) She even calls them “master pattern formation cells”. (82)

In her opinion, “the pattern of the body is encoded in a 2-dimensional folded sheet of fibroblasts into which other cells are recruited – including specialized cell types such as muscle, nerves and blood vessels.” (82) The grid of fibroblasts is able to control the patterning. Bryant furthermore says, that she believes regeneration can be possible in humans as well. There are a few steps that discriminate regeneration and wound healing which have to be identified. The crucial point is, that lizards and axolotls seem to be able to plug back into developmental pathways. These triggers have to be found and can then, hopefully, be applied to humans. (82) Fibroblasts can also be found in human wound healing and play a part in the formation of scars. The key point would be to program them on regeneration instead of repair. (83)

Nevertheless, there is a small difference between the regeneration of axolotl and lizards. Whereas in axolotl, which are able to regenerate limbs, organs and even part of their brain and heart, you cannot distinguish between regrown and original bodyparts, the regrown tail of a lizards resembles the original one morphologically, but is totally different in development. But in both cases a blastema appears, from which the regeneration originates. (82,83)

3.7. Feeling with robotic hands

With your hands you are able to grasp your environment and distinguish shapes and surfaces with your sense of touch. If you were a character a science fiction story, you would be equipped with a lot more. Just think of *Edward Scissorhands*. Or Wolverine in *X-Men*.

Besides this non-human representatives are some others. For example Dr No in James Bond. Being an expert in atomic sciences, he has dealt a lot with radiation and thereby lost his hands. But he got them replaced by bionic metal ones. They provide great strength, but lack skillfulness. Joseph Wiseman, portrayed in Figure 19, mimicked the shrewd scientist in *Dr No* (1962).

For most people it is important to reclaim the function of their lost hand. The sense of touch seems crucial. During the last few years, science has made some progress in this field. In 2009, the SmartHand project, a collaboration between researchers from across Europe, launched a prosthetic hand with extensive sensory feedback. It is based on the phenomenon of experiencing a phantom hand. If you touch the forearm of an amputee, s/he will have the sensation of his/her fingers being touched. (84) And if s/he imagines to move his/her fingers, electrical impulses “are sent down nerve fibres in the remaining part of the amputated arm to activate muscles that would have moved the fingers.” (84)



Joseph Wiseman as Dr. No, Fig. 19

These signals can be trapped by electrodes that are stuck to the forearm and then be transmitted to the motor in the artificial hand. Additionally, SmartHand provides sensory feedback. Tactile information gets translated into sensory feedback, which is transferred to the remaining arm. (84)

Other studies investigate the impact of an artificial fingerprint. “The main focus of the study is to propose a novel skin structure, which mimics the human fingerprints for artificial hands.” (85) These tiny ridges on our fingertips can amplify friction, help to define mechanical information, and let us feel slightest vibrations. In an experiment three different surfaces (flat, edge, round) had to be distinguished by a tactile sensory array. Two different skin covers were applied to the sensory array, both made of silicone rubber: one was flat, the other ridged. In curvature discrimination, the ridged skin cover did better by far. This is important, because different shapes and surfaces require different forces and pressure when grasping an object. (85)

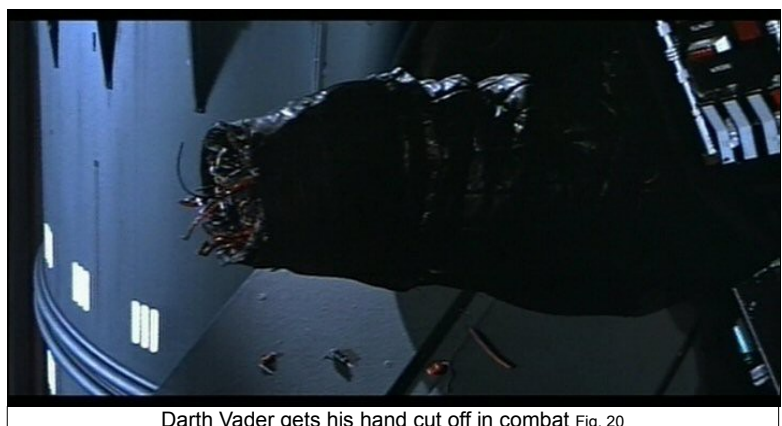
Another, more simple, approach was made by Swedish scientists. They availed themselves on studies from 1998, the *rubber hand illusion*. In their studies, they applied “synchronous touches to the stump, which was out of view, and to the index finger of a rubber hand, placed in full view [...]. This elicited an illusion of sensing touch on the artificial hand, rather than on the stump and a feeling of ownership of the rubber hand developed.” (86)

Participants had experienced an amputation somewhere between the wrist and elbow. At first, they had to undergo a mapping of the phantom hand. During this process, the area on the stump where the sensing of the index finger would be expected was determined. In addition to the experiment, the the scientists seeked physiological evidence with the help of conductive response. (86) When participants were touched on the stump and the finger of the prosthesis at the same time, they experienced it as their *own* finger being touched. (86) Skin conductive response showed “greater psychological sweating [...] when the prosthesis was stabbed with a needle.” (86) With these findings it is possible to design new methods to restore tactile sesinility in prosthesis. It would be a complementary approach to sensory feedback prostheses. (86)

3.8. Intelligent robotic arms

The ultimate goal would be to create a prosthesis that is controlled by the patients brain, just like movements in an able-bodied person would be. To an outsider, the motions should look as natural as possible.

In science-fiction, Darth Vader (*Star Wars*) is one of the most mutilated characters ever known. Most popular is the sound of his breathing due to his mechanic lungs. Though there are numerous mechanical replacements, the focus will be on Darth Vader's arms.



Darth Vader gets his hand cut off in combat Fig. 20

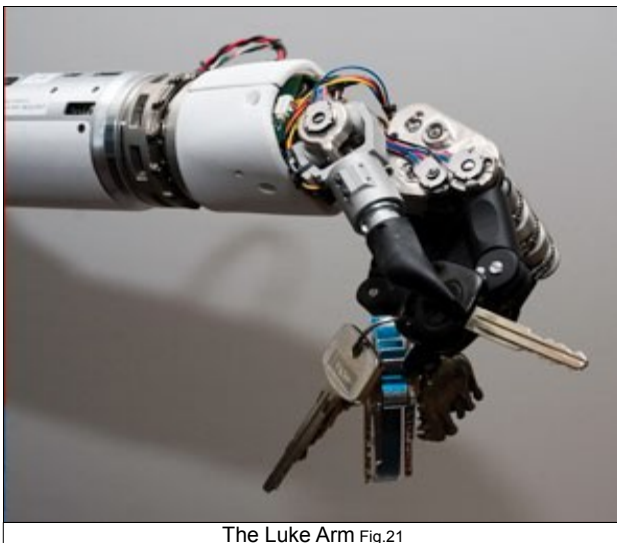
It starts in *Episode II: Attack of the Clones (2002)*, where Anakin Skywalker (who will later

turn into Darth Vader) gets his right arm cut off by Count Dooku. He gets a mechanical replacement. During a duell on Mustafar in *Episode III: Revenge of the Sith* (2005), Obi-Wan Kenobi cuts off Anakin's remaining human arm. When in *Episode VI: Return of the Jedi* (1983), Luke Skywalker cuts off Darth Vader's mechanical hand, which can be seen in Figure 20, and gets cornered by his own son. After pleading with his father, Luke is able to make Vader turn to the Force (also refered to as the light side).

But it was not only Darth Vader who had to suffer losses. In *Episode V: The Empire Strikes Back*, Darth Vader cuts off Luke's hand. Shortly afterwards he speaks the most famous sentence in Star Wars history:

“No, I am your father.” (Episode V: The Empire Strikes Back, 1980)

Being first mentioned in press in 2008, four years later science fiction is becoming science fact. The Defense Department has sponsored the development of the *Luke Arm*, with the purpose to replace the arms which soldiers lost in battle. (87) Figure 21 serves as prove of the fine motor skills of the Luke Arm.



The Luke Arm possesses fine motor control, which enables it to perform precise actions. Another advantage is the modular setup, that make the prostheses usable with any level of amputation. Each joint, shoulder, elbow hand, has electronics of their own. This provides the wearer with 18 degrees of freedom. Even picking an apple off a tree is possible. The controllers for the prosthetic can be found in the shoes of the user. By pushing down the

left big toe, the arm will move outwards. Doing the same with the right big toe will move the arm back in. (88)

Other approaches, for example from British and American scientists, use muscle signals. Two small electrodes in the stump of the user make this possible. They turn electrical impulses into control signals for the prosthesis. This way, it is possible to move every digit individually, pronate and supinate and even offer the possibility for the user to lace his/her

shoes. (89)

In 2002 one of these myoelectric prostheses was adapted to the left arm of a 37 year old German man, who was amongst the first to use this new technique. He could not only move his arm naturally, but was able to adjust velocity as well by contracting or relaxing his muscles more powerfull. His prosthesis was provided by Otto Bock Health Care, global leader in prosthetics. (89)

A corporation in Scotland tried to improve prosthetics as well. In 2007 Touch Bionics invented the iLimb Pulse, a myoelectric prosthesis made out of aluminium that is able to carry up to 90kg. Beside sensory feedback, the artificial limb uses targeted muscle reinnervation (TMR) for steering: peripheral nerves, that were once used for the hand, are replanted into pectoral muscles. If the user wants to move his hand, s/he has to contract certain areas of his chest. (90)

“David Gow, directory of technology for Touch Bionics, puts it this way:

“The i-Limb system is better than a human arm. It is faster and can lift heavier weights than a human arm. It also looks good, has smooth movement, and operates with less noise than existing prosthetic arms. The technology is new and evolving.

“However, we might have to scale the power down to make it suitable for everyone. With something that has a better than human performance, our challenge is ethical.

“A patient would have the potential to hurt themselves or other people with it as it is actually better than a human arm. It could do damage. “ “(90)

Of course, in science fiction movies and literature this would be very convenient, for example in battle scenes. In *I, Robot* (movie 2004; based on Isaac Asimovs novel of the same name, 1950) detective Spooner lost his left arm and lungs in a car accident and gets them replaced by a robotic prosthetic. When later in the movie several robots turn against him, his enhanced arm comes in handy and saves his life.

Unfortunately, these sophisticated prosthesis cost a lot of money. This led to the idea to produce artificial hands, that were affordable even in the Third World. In 2012, Eric Ronning, a student at Wisconsin-Madison University, developed the first prosthesis manufactured by a 3D printer. Its price: 20\$. His idea was pursued and in 2013 a 5 year

old received a prosthesis made from a Maker Bot 3D printer. It was made of polylactic acid (PLA). The advantage is its cost-effectiveness and its ability to be individualized. A 5 year old kid is not fully grown and will need several prostheses in the course of his/her lifetime. Reducing costs plays an important role. (91)

3.9. The power of thought



Christian Kandlbauer in training with his robotic arm Fig. 21

An impressive fusion of technological progress and humanity depicts the innovation of a prosthesis that can be controlled by the power of thought. A young man from Styria (Austria) had a tragic accident in a high-voltage line and lost both of his arms.

After years of surgery and training, Christian Kandlbauer was able to manage his every day life with the help of a myoelectric prosthesis on

his right, and a thought-controlled prosthesis on his left arm. The four main nerves, responsible for arm movement (N. radialis, N. medianus, N. ulnaris, N. musculocutaneus), were redirected to the pectoral muscles (TMR). (92)

After four months of hopeful waiting, first contractions could be observed on the patient's chest, when thinking of moving the non-existent arm. The individual areas regenerated and after two year waiting period, the process came to a stable hold. Now the new ideas of movement, which later had to trigger the prosthesis, had to be learned. It was done with the help of another person, that was positioned behind Christian Kandlbauer and stretched out his/her arms in front of him. The patient had to observe the movements of the arms and reconstruct them in his imagination. Additionally, Kandlbauer had to declare different motions, imagine them and observe *his* hands fulfill his thoughts. (92)

After a few weeks training, the prosthesis had to be connected to the EMG from the patient's pectoral muscles. Already some weeks of exhausting training later, Christian Kandlbauer was able to move his left arm with the power of his thoughts. It was a blessed event, when the patient could report that he felt the water of the shower running down his

lower-arm. This was evidence that even new sensory nerve connections were made. (92) Kandlbauer and his two different prostheses can be seen in Figure 22.

The next step was a hand, that was able to feel. In order to achieve this, microsensors that are able to detect temperature, pressure and vibration, were integrated into the index finger of the prosthesis. This way, Christian Kandlbauer can differ between smooth and rough surfaces and starts to sweat, when he touches a cup of hot tea. (92)

3.10. HEXORR: Hand EXOskeleton Rehabilitation Robot

However what would you do, if you still had your hand, but were not able to move it? This is the problem in stroke patients. After immediate intensive care, a lot of stroke survivors suffer from a hemiparetic hand. (93)

Because the hand represents a major role when speaking of activities of daily living (ADL), rehabilitation robots have been important ever since. “Some of the benefits of rehabilitation robotics include introducing the ability to perform precise and repeatable therapeutic exercises, reduction of the physical burden of participating therapists, incorporation of interactive virtual reality systems, and collection of quantitative data that can be used to optimize therapy sessions and assess patient outcomes.” (93) The ability to flex is often regained, whereas the recovery of extension is poor. In ADL we often need to reach and grasp. In current therapies these movements are trained too little, because the focus is on the proximal upper arm. (93)

“Lately, a number of robots have been developed to provide hand motor therapy. These devices all have similar goals: to develop a training platform that helps patients regain hand range of motion and the ability to grasp objects, ultimately allowing the impaired hand to partake in activities of daily living.” (93) Unfortunately, devices like the endpoint control strategy, and the use of actuated objects (expansion and contraction) display one huge disadvantage: they show limited control of the proximal joints of the fingers. (93)

On the contrary, “HEXORR consists of two modular components that are capable of separately controlling movement of the fingers and thumb. The device acts as an exoskeleton so that the joints of the robot and the user are aligned throughout the allowed range of motion (ROM). This approach allows for multiple points of contact between the digits and the device, which is critical for properly controlling the kinematic trajectory of the

assisted hand movements.” (93) Each finger component has contact to the hand at three different points. Stabilization is guaranteed by several hooks and loop straps. The arm can rest with an elbow support. Hyper-flexion and hyper-extension are prevented by mechanical stops. As a safety measure, the ROM can be limited and adjusted before each trainings session: each joint is extended manually and subjective algesia is being taken into account. Not only is the experimenter able to limit ROM, but velocity. Each session takes 30-60 min. (93)

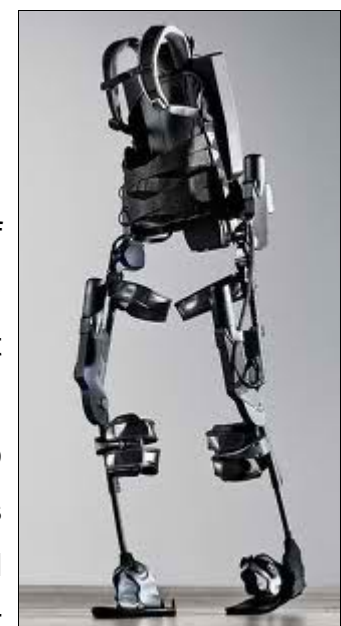
For comparison, unimpaired subjects performed active/passive movements in and outside of HEXORR. Unimpaired subjects reported no difference when asked to compare active movements inside and outside of the device. (93) ROM differed in stroke patients on an individual basis. “The stroke subjects were capable of active extension during the active-unassisted condition and the active force-assisted condition successfully increased the stroke subject's active ROM while maintaining user control of the movements.” (93)

The force-assisted condition enabled stroke patients to increase the active ROM. (93) However, there are a few negative points which need some work: HEXORR restricted to right hands only; there are some difficulties with strapping the intermediate phalanx of the fifth finger to the robot due to different digit lengths; palmar arch modulation has to be considered, because it plays an important role in object manipulation. Nevertheless, HEXORR offers a satisfying system in the mobilization of patients with a hemiparetic hand. (93)

3.11. Wearable robots: Exoskeletons

When first hearing of exoskeletons, one might start to think of insects. In fact, its purpose in insects is to support them from the exterior. They function as protection, support, feeling and protect the organism from dehydration and are built from chitin.

Humans have taken this idea as an example and used armor to protect themselves in a fight. Nowadays, industrial design has taken notice of the idea of exoskeletons and powered exoskeletons are being created. They can be used to support human work and thereby enhance strength or to encourage



Ekso, an exoskeleton by Ekso Bionics Fig.23

therapy in handicapped people. A subdivision of exoskeletons would be orthosis, which have the purpose to support or correct (94), but this paragraph will concentrate on exoskeletons.

In fiction, exoskeletons can be found in the form of super-suits, mostly worn by superheros. Examples would be *Batman* (1939-present) and *Iron Man* (1968-1996). In the comic, its wearer, Tony Stark, is kidnapped and forced to create a powerful weapon of mass destruction. Unfortunately he suffers severe chest injuries. Instead of obeying the instructions of his hijackers, Stark builds an armor and is able to escape captivity.

In the movie, Stark goes to Afghanistan to demonstrate a new missile and is wounded. He is then being imprisoned by a terrorist group called Ten Rings. In captivity, a fellow captive incorporated an electromagnet into Stark's chest in order to prevent a shrapnel from migrating to his heart and killing him this way. Together with his new friend Stark builds an armor, called Mark I, which enables him to escape. It can shoot missiles and repulsor jets and providing a holographic display in the helmet.

Another impressive sci-fi invention is the power loader in *Alien*, displayed in Figure 24. It is able to loft heavy loads and equipped with tools that come in handy when fighting aliens, such as a flamethrower.

In James Cameron's *Avatar* (2009) we can see an AMP (amplified mobility platform) operating. Noteably the fact, that both, the power loader and AMP, need human steering. Though they are impressive technical innovations, they rely on the intelligence of the human user.

Looking at the appearance of exoskeletons in science-fiction it becomes obvious that it attracts attention especially in the fields of military. Unsurprisingly, the exoskeleton from *EksoBionics* could be found on the list of the best technical innovations 2010. In recent days, the invention gives hope to paraplegic, stroke patients and people suffering from Multiple Sklerosis.

In October 2010, a presentation in Munich (Germany) showed how far engineers have come. Amanda Boxtel, a young woman from Colorado, has been paraplegic for 20 years. She was the first to try the wearable robot. Mechanical braces wrap around her legs and in her hands she holds a pair of crutches. (95) Figure 23 shows the bionic suit, which helped her to walk again. Motors in the suit tell the left leg to move forward, when the right crutch

touches the ground. The integrated battery lasts for three hours. Unfortunately, disabled people cannot use the suit on their own, but need guidance. (95)



Power loader from the movie *Alien* Fig.24

An alternative is the HAL-5 exoskeleton, invented by Professor Yoshiyuki Sankai and his team. “The HAL-5 system utilizes a number of sensing modalities for control: skin-surface EMG electrodes placed below the hip and above the knee on both the anterior (front) and posterior (back) sides of the wearer’s body, potentiometers for joint angle measurement, ground reaction force sensors, a gyroscope and accelerometer mounted on the backpack for torso posture estimation. These sensing modalities are used in two control systems that together determine user intent and operate the suit: an EMG-based system and a walking pattern-based system.” (96)

3.12. A prospect: biomechanical energy harvesting

Exoskeletons could one day be of use for everybody. “Biomechanical energy harvesting—generating electricity from people during daily activities—is a promising alternative to batteries for powering increasingly sophisticated portable devices.” (97) It is a form of renewable energy. Windup radios or flashlight take advantage of human muscle power.

But this way, energy can only be produced for a short period of time, because it takes dedicated effort. (97)

On the other hand, biomechanical energy harvesters use energy that is being created without the producer even noticing. It can be extracted during activities of daily living. The method used to harvest the energy is similar to the technique used in hybrid cars: generative braking. By slowing down, kinetic energy is converted into another form of energy that can either be used immediately or stored. To harvest energy using generative braking power generation during swing extension was being used. (97)

“It use(s) a one-way clutch to transmit only knee extensor motions, a spur gear transmission to amplify the angular speed, a brushless DC rotary magnetic generator to convert the mechanical power into electrical power, and a control system to determine when to engage and disengage the power generation based on measurements of knee angle.” (97)

Improvements have to be made, because the metabolic cost has not decreased. The device also need changes in fitting and weight. In the future, biomechanical energy harvester would be interesting in combination with prosthetic limbs. As sophisticated powered prostheses need a lot of energy, it would be accomodating if it was produced by the user him-/herself, enabling him/her to walk further and faster. (97)

4. Healing along the lines of superheroes

When it comes to science fiction, it is not only about new and fascinating technologies. The battle good against evil represents another important issue. In science fiction stories we often find one hero or a whole team of brave fighters. Of course, the protagonists find themselves equipped with incredible powers and stocked with weapons of high potency. The problem is: the other side is endowed with the same cunning tricks, often even more powerful ones. How does anyone have a chance? In most cases, the hero has certain human qualities which help him or her to overcome the technological inferiority: courage, the ability to love, the belief in the good in man, and many more. Unfortunately, before facing victory, our heroes have to go through terrible fights and thereby it is inevitable that they get hurt.

When you are a superhero and you get hurt by the weapons of the dark side, you cannot simply walk into an ambulance. The injuries are far too complicated, sometimes life-threatening or even mortal. But since it is a science fiction story our heroes find themselves in, they are provided with extraordinary medicinal knowledge.

This chapter will focus on a few different methods of healing, regenerating and gaining additional power plus what we can learn not only from superheroes but also from the animal kingdom.

4.1. Medication for healing wounds

Since the topic of bone healing has already been covered, this paragraph will take a look at healing wounds, with special emphasis on skin regeneration and repair. Table 1 represents a list of different drugs used in various science fiction stories.

Additionally, in some science fiction stories drugs that enhance human capabilities exist. One example would be the Super Soldier Serum (or Super Soldier Formula) in *Captain*

America (1941-present), which turns Steve Rogers into a superhero. Not only does it improve physical capabilities, but also mind, healing and eye sight. It would also explain the fact, that super heroes do not tend to age. Nevertheless, when used excessively or in high potency, side-effects, like mental deficiencies, can occur. (101)

Of course, it is human nature to strive for improvement. We always want to be better, faster, stronger, ahead of the others. Especially in times of war this fact gains in importance. A drug used was *Pervitin*, a methamphetamine that kept the soldiers alert and efficient. Nevertheless, it had to be accepted that *Pervitin* had severe side-effects. Regeneration time increased and deaths have been reported. (102) Also the use of cocaine has been reported. Its purpose was to keep soldiers fully operational and raise their ego.

Drug	Science fiction reference	Effect/Application
Aqua Cure	Resident Evil (frist edition 1996)	Balm that rapidly heals open wounds
Bacta	Star Wars (1977)	A liquid similar to the body's fluids. It can be used on cuts and burns, but also helps with cellular regeneration. In the case of major injuries used as healing bath.
Cell Activator (Chip)	Perry Rhodan (1961)	Cell regeneration. Immortalizes the wearer.
Dittany	Harry Potter (1997)	A lotion that is able to occlude wounds immediately.
Heal Jelly	Trauma Center (2005 – 2010)	For small cuts. Can stop bleeding from larger wounds.
Sarcophagus	Stargate (1997 – 2011)	Used for wounds and major injuries but also to extend life span. Can raise the dead.
Wax (recovery) bath	Wanted (2008)	Increases number of white blood cells and thereby encourages recovery.

Table 1 (98-100)

But how do these fictional inventions find their way into everyday life? Alas, even modern science has not yet come up with a healing or recovery bath, though there is excessive research in fields of recovery and anti-aging. Nevertheless, some striking parallels exist considering skin regeneration and scar management.

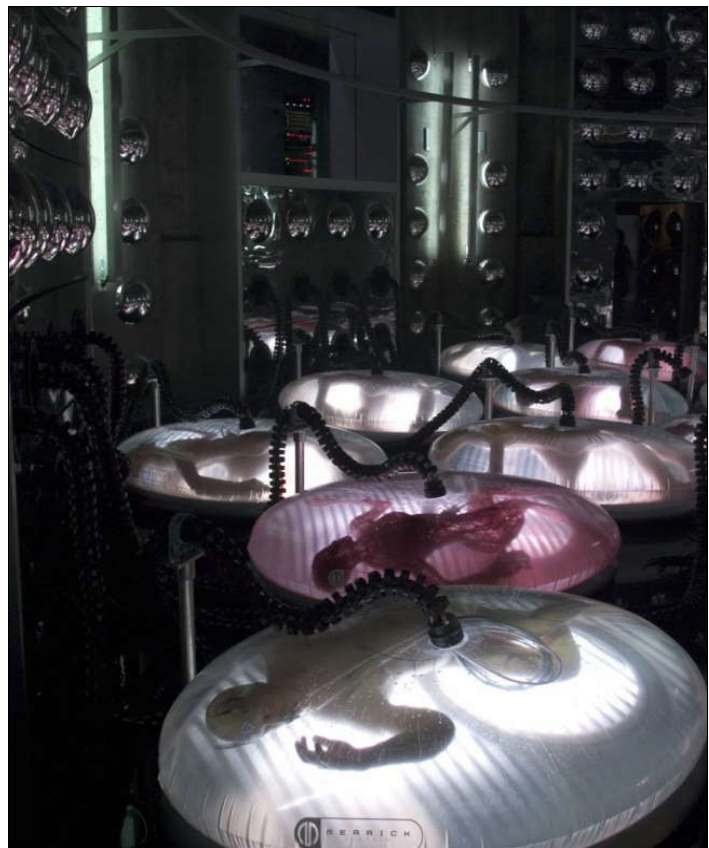
4.2. Spare parts person

Despite the efforts of modern science in the regeneration of limbs and organs, most patients are dependent on organ donation or mechanical supportive devices. In Chapter 3 we have already come across the possibility of transplanting extremities, or otherwise the use of robotic devices. Science fiction offers another, terrifying alternative: spare part persons. The movie *The Island* (2005) makes organ harvesting a subject of discussion. In the movie, people are brought to an island under the pretext that the rest of the world is not safe anymore. But once on the island, they are misused as donors or for surrogacy. Note, that the plot takes place in 2019.

In Figure 25 the methodical breeding of new donors is displayed in a screen shot.

In times where cloning has reached reality, a scenario like in *The Island* would technically be imaginable. The need for organs increases exponentially. A sad evidence for this is an event from 1999 when a kidney was for sale on an internet corporation which quickly reached \$7 million. (103)

Atkinson (103) proposes the improvement of xenotransplantation



Breeding humans as spare parts person in the movie *The Island* Fig.25

(transplantation between different species). According to Atkinson, the problem of hyperacute graft rejection (HAGR), where antibodies destroy the blood vessels of the donor organ which mortifies this way, can be overcome by using transgenic pigs. Regrettably, the fear of the HIV virus passing from animals to humans put Atkinson and his ideas at a crossroad. (103)

A different approach to overcome the gap of supply and demand is to cultivate organs in vitro. Once this is manageable, where will it lead us? Will we be able to replace every organ and thereby improve our bodies and be immortal one day? Where would you draw the line?

Most people agree with the idea of organ donation, as long as there is medical reason behind the action. Though some people are more prudent: The question is what happens, when part of another person is integrated into oneself? Will there be a change in personality, preferences or peculiarities? What surely can be said, is that people tend to be more suspicious when they think about the possibility of donating their eyes, brain and in some cases genitals. (104)

Particular importance is ascribed to the brain. The brain is what makes us special.

The question is: What happens if we connect our brain to electronic devices? Where does the human being end and the machine begin?

4.3. *Human, robot or cyborg?*

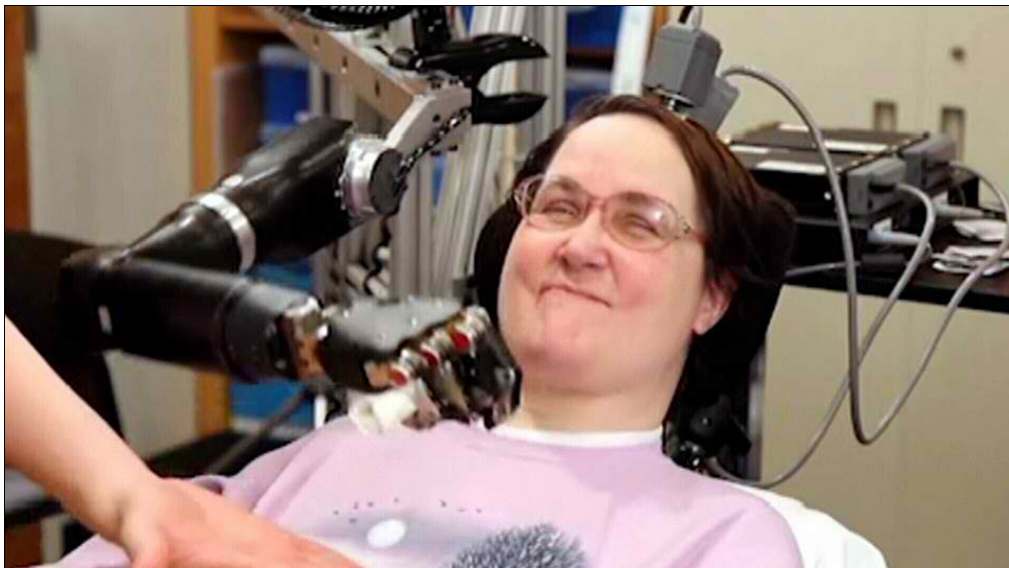
As a matter of fact, the connection between brain and computer is common use. Just think of cochlear implants, Deep Brain Stimulation and things like neurofeedback and neuroprostheses, which have been mentioned in Chapter 3. In 2009 Ray Kurzweil, futurist and inventor of the electronic keyboard and the voice-recognition system (105) , predicted:

“Within two or three decades our brains will have been entirely unravelled and made technically accessible: nanobots will be able to immerse us totally in virtual reality and connect our brains directly to the Internet. Soon after that we will expand our intellect in a spectacular manner by melting our biological brains with non-biological intelligence. “

(105)

In 2004, electrodes were integrated into the brain of a 24 year old paralysed man, who then was able to control a computer by his thoughts. Technology evolves quickly and maybe soon we will be able to implant chips into healthy brains, that make it possible to extend memory or intelligence, give us the possibility to read thoughts or detect lies. (105)

In 2009 the photo of Jan Scheuermann, shown in Figure 26, was in newspapers around the globe. Two electrodes were placed in the part of her brain, which controls the extremities. The big breakthrough is the fact, that scientists succeeded in translating electronic signals from the brain into signals that can be read by the computer more accurately. This way, Jan Scheuermann is able to perform movements like grasping and stacking, and most importantly: rewarding herself for her courage and endurance by eating a chocolate bar all by herself – taking and leading it to her mouth by the power of her thoughts. (106)



Jane Scheuermann, taking a bite of a chocolate bar, which she led to her mouth by herself Fig.26

Technologies like this challenge our moral categories. Not only do we have to redraw the line between human and machine, but also between body and mind. The ability to replace organs by machines or artificial organs makes us a compound of human and machine. We turn into a cyborg and thereby become somehow part of science fiction. But it always depends on the context an artificially enhanced human is seen in. Whereas modern

prostheses are commonly accepted, someone with high functional leg prostheses may be considered a machine in a sports event. But in everyday life, s/he is considered to be “morally responsible for his [her] actions as any other person.” (105)

In an ethical sense, the mind is what makes us a person and distinguishes us from a machine. “Ethical theories consider the possession of some minimal set of cognitive, conative and affective capacities as a condition for personhood.” (105) According to Schermer, brain machines do not turn us into a cyborg or monster, because they do not affect personhood. (105)

4.4. Human-machine-interface



Original Tricorder from Star Trek Fig.27

Even though the fusion of human and machine scares us, technology helps us a lot in our daily routine. The progress of networking and the evolution of the internet has made our lives incredible fast. Due to the breakthrough of smart phones we are not only easily attainable, but have access to information anywhere at any time. This way, normal people turn into specialists in nearly every field. Medicine included. Via mobile phone and with the help of various applications (*apps* for short)

you can count your steps per day, be reminded to drink a glass of water every so often, keep a diary on your eating habits, your blood pressure or interpret your latest laboratory findings.

Star Trek (1966–1969) came up with a similar gadget way before tablet computers and smart phones flooded society: the *Tricorder*, shown in Figure 27. It is able to analyze vital signs and give information about diseases. This idea is so appealing, that the X Price Foundation announced a \$10 million prize money for the invention of a technical device that is able work as good as council of approbated physicians. (107)

This approach is aimed to give the patient information about blood pressure, pulse, ECG, respiratory rate. In addition, it should be able to measure blood glucose as well as other

laboratory findings. But can this be the solution for overcrowded ambulances?

In the hands of a layman it is more likely to confirm anxiety and doubt, and thereby harming the relationship between doctor and patient. Nevertheless, a technologically advanced, reliable *Tricorder* would be of great value to a lot of emergency rooms. But as in its original form, it has to be used by a professional. (108)



Rudy, the Robodoc Fig.28

A similar project, that may remind of holograms from *Star Wars*, started in 2004 and was tested at the University of California Davis Medical Center. There you can see the gadget shown in Figure 28: a 1,68m tall robot called *Rudy* riding through the aisles of the hospital. He is equipped with a camera that can zoom in, a TV screen, a microphone and can be operated from anywhere via computer. The idea is that patients after surgery like to see the doctor who operated on them. Since this is not always possible in person, the university came up with *Rudy*. Currently they conduct a study whether there is a difference in patient health outcomes between patients who postoperational see their doctor in person and

patients who are visited by *Rudy*. (109)

4.5. Robodoc

There was a time when everyone thought technology was going to replace human work in all fields. In science fiction, we come across autodocs in Larry Niven's story *Ringworld* (1970). For orthopedics autodoc is called ROBODOC and has been introduced in the 1980s. The goal was to achieve a better surgical outcome. ROBODOC was commonly used in Germany, but has gone out of style due to safety concerns. (110) "The idea was to bring computer-aided design and computer-aided manufacturing (CAD/CAM) into the operation room (OR) for an accurate placement of femoral prostheses." (111)

Its purpose was to help find the appropriate size and type of femoral implant and machine

the cavity. “It consists of a preoperative planning computer workstation (called ORTHODOC) and the ROBODOC surgical assistant, which has a five-axis robotic arm with a high-speed milling device (end effector) connected to the tip of the arm via a force torque sensor.” (111)

Before the procedure, three titanium screws are inserted into the greater trochanter, the medial femoral condyle and the lateral femoral condyle. Then a CT is taken, which can be matched with the patient's position on the OR table. The matching is called registration. Because the placement of titanium screws is accompanied by an additional surgery, surface registration, where no fiducial is needed, was used by ROBODOC since 1999 as an alternative. (111) The first clinical study examining ROBODOC was from 1994-1995. In 136 hip replacements it could be shown that “fit and positioning of the femoral component were significantly better in the ROBODOC group.” (111) A German study indicates problems with ROBODOC. Reports of technical complications underline the importance of a human behind the machine. ROBODOC is an active system, but still needs a well trained surgeon who is familiar with the procedure and possible complications. (111)

ROBODOC represents one of the three categories for robotic systems: it is autonomous, meaning it does not need assistance but can be stopped intra-operatively via a shut off switch. The other category is haptic or tactile. These robotic systems need the guidance of a surgeon and are far more commonly used. (110)

An example would be the Robotic Arm Interactive Orthopedic System (RIO), which is used for unicompartimental knee replacement. With the help of CT imaging a three dimensional model of the knee created, which helps the surgeon to decide on the sizing and placement of the prostheses. An exact pre-operational plan will guide the system. Because the cutting zone is pre-defined, the system will stop once the surgeon comes out of a determined zone. This gives the surgeon little scope. Nevertheless, the advantages are smaller incisions due to higher precision, which results in shorter recovery time. It is also possible to perform surgeries with the help of RIO on outpatients and it is an excellent assistance for less experienced surgeons. (110)

Passive robotic systems make up the third category. These help to perform surgeries with the help of computer navigation. They provide detailed information throughout the operation, but it is up to the surgeon to follow the suggested instructions. (110)

Progress in 3D technologies have encouraged the development of navigation in

orthopedic surgery. "Navigation is a passive system, which does not perform any actions on patients, but only provides information and guidance to the surgeon who still uses conventional tools to perform the surgery." (111)

Optical and magnetic sensors can be used to target bones, implants or surgical tools.

There are three types of navigation in total hip replacement:

- CT-based: preoperative CT-images are used for planning the surgery. Coordinates from the 3D reconstructed CT-images and anatomical landmarks are matched.
- Imageless navigation: a dynamic reference frame is attached to the pelvis and pelvic coordinated can thereby be created intraoperatively.
- Fluroscopic navigation: same procedure as in imageless navigation, but positions are registered via real-time x-ray. (111)

Hart, Janecek, Chaker and Bucek (112) published a study in which 120 total knee arthroplasties were compared. 60 patients were treated with the standard technique and in 60 patients OrthoPilot Navigation was used. OrthoPilot is a CT-free navigation system. It is based on infrared data transmission between pointers and a camera. (112) A deviation of 2° was accepted. In the standard group 18 cases showed a larger deviation, in the OrthoPilot group it were 7 cases only. Because of its accurate reproduction of anatomic axes and angels, OrthoPilot represents a helpful navigation system for the inexperienced orthopedic surgeon. (112)

The positive effects of robotic systems are a shortened surgery time, with less post-surgical complications and a shortened hospital stay, which all over, minimized costs.

On the other side, robotic systems do have limitations. In most cases, the systems are rather expensive. The cost-benefit ratio is better for large hospitals. In additions, the costs for hardware calibration and software updates have to be considered. The lack of long term results and studies is another crucial point that has to be deliberated. (110)

Another robotic system with a different targets is computer assisted tumor surgery (CATS) which has its origin in neurosurgery, but is now used in orthopedic tumor surgery as well. The aim is to restate two dimensional information into a three dimensional model of the tumor. In former times, the patient had to relay on the expertise of the surgeon and means like fluorosan assistance, which would mark the tumor. New technologies offer an

improvement in accuracy and function, and make it possible to create custom-made implants. (113)

The need for great precision is extremely important in pelvic or sacral regions, but also when the tumor has afflicted joints. In such cases the margins around the tumor have to be chosen according to the golden rule as much as necessary - as little as possible., in order to preserve the hale bone.

Via the fusion of CT and MR images, a three dimensional model is accomplished, which gives the surgeon information about the anatomy and extent of the tumor. Furthermore, the image can be sent to an implant company, which then will build a custom-made replacement if needed. Then, the resection margins will be marked and the resection will be planned. The image to patient registration in the OR will correlate the image-information with the real time situation. When the resection is performed, results can be compared the the results of the pre-surgical plan. (113,114)

Although this method is in its early stages, it is promising. Not only does it offer a good possibility for preserving bone, but it also represents an alternative to intra-operative CT imaging and radiation because it is in real time view and provided less radiation. Despite the lack of long term results, it is thought the the overall outcome is better than in the standard surgery. (113)

5. Knowledge exchange

Not only does science-fiction have an influence on medicine, but vice versa. This last chapter will present a medical field that contributed to modern day science fiction filming methods. But it will also outline the progress in knowledge exchange that modern technologies made possible.

5.1. Gait analysis

In most cases mentioned above it was medicine that was inspired and learned from science fiction. Science fiction often takes approaches of advancing ideas of every day life and takes them to another level and ask for the impossible. But in some cases it is medicine that helps out science fiction.

One such way is motion capturing. In medicine it is better known as gait analysis. This is a way to precisely observe and analyze human walking patterns. It can help to unravel pathologies. But it is also used in sports medicine in order to help athletes improve their run and avoid injuries. This method became widespread in the 1970s, when video cameras were of common use. (115)

Since science fiction is always on the strive for better and more realistic effects, it was a question of time (and technological development) until the movie industry discovered motion capturing. First used for video games in 1995, it is widely spread nowadays.(116)

It attracted special attention since the release of *Avatar* (2009). Most of the plot takes place on a foreign planet and the main characters are the Na'vi. They do resemble humans in some parts, but they are much taller, have a tail, different facial features and can perform impressive movements. To create these creatures in a computer program would have meant excessive work and the outcome would not have been satisfactory. Therefore, real actors performed on a motion capture stage with a lot of cameras filming them from different angles and viewpoint. Additionally, they had to endure a camera fairly close to their face, so that mimics could be captured. Figure 29 gives an idea of how the mimic of the actors was translated into that of the computer-build Nav'i. This technique was a big step forward also because new technologies made it possible to transfer their

performance onto screen in real time. This made it easier to direct scenes. (117)

When in 2002 real time motion capture systems was first used in *The Lord of the Rings: The Two Towers*, the actor playing the part of Gollum had to endure a suit with numerous markers everywhere, which then were tracked by cameras.



5.2. Virtual interactive systems

The advantages of human and machine consistent together have already been outlined. This way it is possible to complement one another. But it should be underlined, that the responsibility is always ensured by the human steering.

Another task which machines can accomplish successfully is the support in education. Since technologies are developing rapidly, new learning platforms are created. The human skeleton can be studied on screen, it is possible to zoom in on every joint. The user is able to look at it from different angles, move joints and learn about the skeletal system, muscles, joints and ligaments interactions. In addition, 3D joints give us the opportunity to simulate kinematic and dynamic situations. With the help of CT images and 3D reconstruction it is possible to visualize the individual situation that will await the surgeon during surgery. Type and size of prostheses can be chosen preoperatively and thereby the surgery can be optimized. Difficult anatomical situations can be studied.

In 2011 a team of Chinese orthopedists published a study in which they studied the lumbar

plexus. This is a delicate region in retroperitoneal approaches. With the help of 3D reconstruction of the lumbar plexus and its adjacent structures, they were able to find a regularity to the formation of the lumbar plexus and defined certain landmarks that can help during surgery. (118)

The development of virtual reality has added up to recent educational approaches. The concept of virtual humans tries to combine physiological properties with engineering advances. In respect to orthopedics, it helps in studying anatomical structures as well as analyzing biomechanical features and surgical procedures. “Adaptable anatomical models including prosthetic implants and fracture fixation devices and a robust computational infrastructure for static, kinematic, kinetic, and stress analyses under varying boundary and loading conditions are incorporated on a common platform, the VIMS (Virtual Interactive Musculoskeletal System).” (119) It can also provide a database for comparative purposes. The models can also help patients in rehabilitation to understand what has happened in their body and how different therapies can help to regain original form. Additionally, virtual laboratories can be created in which research findings can be shared and discussed. Information about development and testing of orthopedic implants can be passed on easily, preoperative planning strategies can be compared worldwide. (119)

The worldwide interaction and networking is an important aspect of modern medical research and offers the patient more security via evidence based medicine. Telemedicine has become popular in recent years. Contrary to the common idea of a surgeon performing an operation via computer, being thousands of kilometers apart from the OR, the term refers to the use of telecommunication and information technologies to improve access to medical services in outlands. (120) Three categories can be distinguished: store-and-forward, remote monitoring and (real time) interactive services. Store-and-forward telemedicine refers to the ability of a medical specialist to evaluate medical data at any time s/he wants. The patient has not to be present. Remote monitoring offers the opportunity to keep track of medical data of patients remotely. This is of common use in patients with chronic diseases. The last category, interactive service, gives the patient the option of real-time interaction with his/her physician. (120) E.M. Foster introduces the idea of diagnosing and treating patients over a long distance in his story *The Machine Stops*

(1909). As another aspect, telemedicine can also be useful in emergency cases, where certain specialities are needed.

In my opinion, it is the development of these networks that is important to provide excellent medical care. The interaction between handler and patient is significant but also the exchange of expertise. Once again, technology can only form the framework of a process that has to be steered by a human. We should not be scared of technical development, artificial intelligence taking over but embrace the opportunities its progress provides.

6. Results

Coherences were already outlined in the first chapter, which deals with the most popular themes in science-fiction. In 1996 the picture of the cloned sheep Dolly was in newspapers all over the world. But the idea was already aroused in 1932 in *Brave New World* by Aldous Huxley.

The main part of the thesis focuses on bone healing, robots and prosthetics and ethical issues like the spare parts person. This division has come about because of the needs of most main characters in science fiction stories. Wolverine represents the perfect role model. As one of the *X-Men* he is invulnerable due to his sped up healing facilities and has a skeleton made of Adamantium, which is also known to be indestructible. Parallels can be drawn to bone grafts. Whereas the story of the Marvel comic-superhero started in 1963, autograft transplantation is known science the 1880s. New approaches in science try to imitate ECM and enhance bone healing. Another milestone in bone healing has been achieved in 2009. The Defense Advanced Research Projects Agency (DARPA) funded a project known as fracture putty. This material can substitute damaged bone and is particularly suitable for complex fractures. Clifford D. Simak already dreamed of advanced healing in 1962. In his novel *Time is the simplest thing* he mentions gobathian, an alien drug. It is able to heal broken bones and even regrow organs. Another method to replace bone would be to print it. The idea was aroused by Philip K. Dick in 1964 in his novel *Cantata 140*. Dick talks of artiforgs, artificial organs. Since then, the idea of printing organs appears again and again. For example in *The Fifth Element* (1997) or the screen adaption of Dick's original *Repo Man* (2010). Extensive research made this idea possible, when in 2012 a 83year-old woman received a lower jaw transplant made of titanium, that was manufactured by a 3D printer.

But science fiction does not only regrow and heal, it enhances. Thereby the wildest recreations emerge: a young boy lacking arms, but having scissors instead (*Edward Scissorhands* (1990)); Steve Austin, who gets one arm and both legs replaced (*The Six Million Dollar Man* (1974-1978), based on *Cyborg* by Martin Caidin (1972)) or famous Luke Skywalker. The history of prosthetic limbs dates back as far as 3500BC. The Rig Veda tells the story of Vishpla, a warrior queen, who lost a leg in battle. It was replaced by an iron leg, which empowered her to return to combat. Modern prostheses turn amputees into

supermen, by attaching propellers to their feet instead of normal artificial limbs, or enabling them to climb mountains as fast as ibexes by imitating their hooves.

An arm prostheses which carries the science-fiction origin in its name is the *Luke arm*. It was first mentioned in press in 2008 as a part of the DARPA's prosthetics program. The prostheses offers more agility than ordinary ones. Fine motor control provides fine motor skills. An alternative to all healing methods and bionic devices would be to regrow bodyparts. In 1969 Frank Herbert wrote the novel *Dune Messiah*, in which he mentions the axolotl tank. It is able to regenerate, but even reshape organic material. Body parts can already be reared in vitro, but the goal would be to send cells back into the developmental pathway.

An utterly different topic deals with exoskeletons. In comics and science-fiction superheroes often appear in a characteristic suit. It appears in different variations, for example to shield the wearer from radiation and vacuum. The focus is on suits that increase strength and provide invulnerability. Such can be found in *Batman* (comic 1939). In real life exoskeletons enable handicapped people to leave their wheelchair and walk on their own, as first reported in 2010. Superheroes also need superpowers. Steve Rogers gets dosed with supersoldierserum, which turns him into *Captain America* (1941). Unfortunately such experiments with soldiers have been reported since World War I, during which soldiers were given metamphetamie to stay alert and efficient.

Nowadays we are used to a huge technical progress. Telegraphs turned into phones, turned into mobile phones, turned into smart phones. These provide a wide range of functions and applications. In 2011 the X Price Foundation challenged scientists and inventors to come up with a device that is able to diagnose patients. The reference was provided by *Star Trek* (1966-1969) – the Tricorder. The competition is still going on, but different applications for smart phones have come onto the market, but have not been approved. The next step would be to develop a technical device that it not only able to diagnose autonomously, but also perform surgical operations. Autodocs have been introduced in Larry Niven's story *Ringworld* (1970). For orthopedics autodoc was called ROBODOC. Introduced in the 1980s, it was thought to rapidly replace woman/man in the OR. Whereas the idea of full automatic robotic systems was abandoned, surgery still makes use of haptic devices. Telemedicine is included in this field of topics. The origins of telemedicine are difficult to evaluate, because it can be broadly defined. Even knowledge

exchange via phone can be considered telemedicine. Nowadays images can be exchanged over huge distances in just a few seconds and videoconferences can be held. It is a way to provide outlands with necessary support. In 1909 (*The Machine Stops*) E.M. Forster comes up with the idea of a medical device that is able to diagnose and treat people over a distance.

In conclusion, all these technical devices and scientific achievements corroborate the hypothesis that science-fiction and medical science are closely connected and influence each other.

7. Discussion

The issue of this thesis was to relate science fiction with medical science, thereby concentrating on the special field of orthopedics. Using extensive literature research, it could be shown that science fiction and medical science are correlated. Autografts and prosthetics appear in scientific literature before they found their way into science fiction stories. But for most of the part, researchers have taken science-fiction as an example. Promising are those ideas, that have been developed and projected into the future.

The purpose of science fiction literature is to create alternative world and futures, and thereby remodeling history. Scientific fact and science fiction are often related. But, according to Rabkin E.S. (121), only 3,75% of science fiction stories, which have science as their dominant topic, deal with medicine. Therefore, the approach to compare science fiction with realistic medical development was new.

Undoubtedly, The coherence in other scientific fields cannot be denied, as outlined Chapter 1. But few stories deal with medical science only. Preferably, medicine represents a small part of the story. Important to notice is the fact that science fiction does not only deal with technological devices and inventions, but also addresses social and emotional problems. Rabkin E.S. (121) states that a lot of stories depict our fear of physicians, especially when they seem omniscient. Due to the fact that science fiction is a literature of stereotypes, sometimes doctors appear to be god-like. Thinking of Mary Shelley's *Frankenstein* (1818) this phenomenon becomes clearer. The effort of the main character aims at creating artificial life, which succeeds in the end. But the story tells also of the problems and responsibility which comes along with such greatness.

New scientific approaches and technologies should always answer in a good cause. But with evolving possibilities occurs recklessness and arrogance. A good representative is the diversely discussed topic of cloning, which has already been approached in Aldous Huxley's novel *Brave New World* (1932) and has later been seized by authors like Frank Herbert. The process became scientific fact in 1996, when the sheep Dolly was cloned. It seemed as if a new era was beginning. But with it came a lot of ethical issues. By creating new life intentionally, did physicians play God? Kirby D.A. (122) gives a good summary on the history of eugenics in science fiction and also integrates modern history. Once more, science fiction tries to teach us a lesson. By forcing to correct our genome and eradicating

the irregular, we manipulate nature which can culminate in the extinction of mankind.

The main part of this thesis deals with the context between science fiction and orthopedics. Considerable is the fact, that with the exception of autografts and prosthetics all achievements appeared in science fiction before becoming scientific fact. Especially in the fields of bone healing huge advances have been made. Researchers were guided by ideas of Clifford Simak and Philip K. Dick. The need for effective bone healing and repair in science fiction and reality, respectively, often originates in war sceneries. A lot of the projects on bone healing being funded by the military forces stresses this circumstance. Additionally, the invention of suits that enable soldiers to walk longer distances and carry heavier loads derived from operational zones. The accomplishment can be transferred to medicine, where exoskeletons can help paraplegic people.

The close relationship between science fiction and medical science can be seen in prosthetics. New electronic prostheses bear the name of science fiction heroes (Luke Arm). The idea to extend human life by integrating robotic devices is a main characteristic of science fiction. By attaching robotic arms and legs, medicine and technology combine to not only create an intact human being, but to enhance human capabilities. But along with these possibilities come ethical issues. Schermer M. (105) discusses the problems that come along with extended memory, enhanced intelligence and the ability to read thoughts. Our definitions of personality will have to be revised. Science fiction sometimes shows us a society, where robots and cyborgs are subprime. Either they are used as attendants or excluded and persecuted for their otherness. While technology becomes more sophisticated and robotic devices will find their way into everyday medicine, we have to reschedule our ideas of integrity. Promising seems the idea of Schermer M. (105) that the discrimination whether human or machine has to be context bound. An athlete with an highly-developed artificial limb prostheses may be considered too much machine to participate in common sport events, but can otherwise be regarded as a human being with all his/her rights.

Eventually, even orthopedics has not been spared the fear of robots overtaking. When in the 1980s ROBODOC was introduced, the orthopedic world dreaded that surgeons would soon be replaced by robots. The advantages seemed obvious: less expenses, more precision. But it turned out not to be so easy and luckily surgeons these days are not

unemployed. Technology is not used to the individuality in human bodies. It is the interaction between surgeon and robot that is encouraging.

7.1. Limitations

At the very beginning, the question what fields of medicine should be included had to be faced. Although the title puts a special emphasis on the musculo-skeletal system it was decided to stretch the meaning, with the result that Chapter 3 makes a foray into neurosurgery and regeneration medicine, and Chapter 4 includes pharmacology and ethics. The introduction at the beginning may seem out of place, but it gives the reader a chance to read up on the subject. Another problem is the fact, that there is little reference material concerning the context between science fiction and medical science. The sparsely found papers were either too general, concentrating on the impact of progressing technology on medicine, or too precise, only dealing with a subchapter represented in this thesis. This way, the science fiction literature and movie had to be related with medical science from scratch. To accumulate enough scientific work, no limitations considering the date of publication were made. This means that the resources date from 1902 to 2013. Despite the topicality of the sources of information, some technologies have not yet gone through scientific studies, meaning that it had to be relied on newspaper articles and websites. This of course, poses a certain risk of misinformation.

Summary

In conclusion, the hypothesis that science fiction has an influence on medical science could be supported. The secret is to take a promising idea and project it into the future. History has shown us that how ever far-fetched approaches may seem, they might come true some day. Even though medicine has come a long way, we have to be aware that we do not know everything. Misconceptions exist and we still have a lot to learn. As ridiculous it may seem, science fiction can be a source of inspiration what with evolving technology. Furthermore, science fiction does also teach us a lesson on mindfulness. Although the urge to cure diseases and conquer ageing and death are omnipresent, we have to be aware that these processes belong to life, just as growing and developing does. Most importantly, we have to control our creations and never forget that the responsibility for all actions always lies upon a human mind.

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