Robotics in neurosurgery activity:

Impact in the workforce

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Resumo

Título: Robotics in neurosurgery activity: Impact in the workforce

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A Robótica e Inteligência Artificial estão a ganhar cada vez mais relevo em variadas indústrias, e a da saúde não é exceção. Apesar de a neurocirurgia apresentar desafios particulares à implementação de algumas tecnologias, a sua natureza exigente também se pode considerar uma oportunidade para incorporar mais inovação na atividade, potencialmente aliviando o trabalho e esforço das equipas cirúrgicas.

Através de uma revisão de literatura e da condução de entrevistas com neurocirurgiões de vários países , este estudo propõe-se contribuir para entender os impactos da robótica nos recursos humanos e melhorar a gestão de Recursos Humanos face estas tendências. É notório que as equipas cirúrgicas já estão a evoluir, tornando-se mais multidisciplinares. No entanto, verificou-se que os sistemas de gestão de performance estão pouco desenvolvidos o que torna pouco claro como é que a distribuição de tarefas irá evoluir. Ainda assim, é clara a necessidade de agilizar a sinergia entre a saúde e fatores externos que a influenciam. Tendo isso em conta, implicações e recomendações foram feitas através deste estudo, focando o desenvolvimento de regulamentação e a inovação na educação e gestão do "médico do futuro", com os principais objetivos de não só melhorar a entrega de cuidados de saúde como também a experiência de trabalho das equipas cirúrgicas.

Palavras-chave: : Robótica, Neurocirurgia, Equipas Cirúrgicas, Inteligência Artificial, Recursos Humanos, Estrutura Organizacional, Treino, Mudança na distribuição de tarefas

Abstract

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Robotics and Artificial Intelligence are gaining relevance in various industries and healthcare is not different. Even though neurosurgery shows some constraints to the implementation of technology, its demanding nature can also be considered as an opportunity to incorporate more innovation in the workflow, taking some pressure off neurosurgical teams.

By reviewing existent literature and conducting interviews with neurosurgeons from different countries, this study aims to explain the impacts of robotics in the human resources and to improve its management when facing these trends. It's noticeable that surgical teams are evolving, becoming more multidisciplinary. Nevertheless, it was verified that performance management systems are undeveloped what makes unclear how the task distribution will evolve. Apart from that, the need to expedite the synergy between healthcare and external factors that influence it is clear. Keeping this into consideration, implications and recommendations were made, focusing on the development of regulation and on the innovation in the education and management of the "doctor of the future", with the main goals of not only improving patient care but also the work experience of surgical teams.

Keywords: Robotics, Neurosurgery, Surgical Teams, Artificial Intelligence, Human Resources, Organizational Structure, Training, Task Shifting

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List of Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
CT	Computed Tomography
FDA	Food and Drug Administration
H1	Hospital N (N=1,2,3,4,5 or 6)
MRI	Magnetic resonance imaging
NS	Neurosurgeon N (N=1,2,3,4,5 or 6)
RS	Remote Surgery
TAM2	Technology Acceptance Model 2
TRA	Theory of Reasoned Action
UK	United Kingdom

Chapter 1

Introduction

Neurosurgery has always been regarded as an advanced form of surgery and has pioneered different technologies. Various techniques have been transforming the area, like deep brain-stimulation(Goering et al., 2021), stereotaxic surgery and more recently AI(Manuel Gil Martins, 2022), expanding the limits of medical innovation and improving patient care. At its core, it is the medical specialty dedicated to spinal, skull and brain disorders and it is a demanding area, responsible for "balancing strict precision requirements and the limitations imposed by an operative field surrounding the delicate brain and spinal cord tissue" (Ezzat et al., 2023).

Despite its anatomical limitations, it has been gaining relevance. The use of robots promises to offer multiple advantages such as decreasing fatigue, the ability to reach locations humanly impossible or performing minimally invasive surgery (Maan Al-Salihi et al., 2022), increasing success rates and minimizing recovery time (Ezzat et al., 2023). In healthcare such as in other industries, the evolution of technology and robotics has revolutionized the job industry which means that job descriptions as we know them now will change and are continuously evolving (Qureshi & Syed, 2014). Surgical teams are becoming more and more multidisciplinary, including, among other, doctors and engineers (Attanasio et al., 2021). Nevertheless, there is a lack of clarity on how future surgical teams will really look like, with the implementation of advanced robotic surgery. In this sense, this dissertation aims to understand how technology will impact these teams and their management, with the main goals of understanding how they will be formed; what will the tasks distribution between doctors, technical professionals, and robots be; and, how the training and education of future and current surgeons will evolve. The following research questions were outlined to guide this work:

1. What type of technologies are used at the moment and how are they implemented within

the surgical teams?

2. What are the main prospects for changes in technology and how are they believed to shape the teams?

3. How will these teams be prepared for the future medical workplace?

As main research method interviews were conducted with neurosurgeons across the globe, as part of a qualitative analysis, exploring variability across different between countries, sectors and even personal and professional experience. This was supported by the review of relevant literature.

Chapter 2

Background

Based on the literature reviewed, this chapter portrays the present reality of technology used in the neurosurgery activity and in human resources practices. Furthermore, it is detailed the main prospects for technology in the concerned healthcare area as well as how it may impact the management of human resources.

2.1 Robotics in Healthcare

2.1.1 Robotic surgery

The implementation and use of new technologies such as robots in healthcare is an emerging topic. For some time, robots in medicine were mainly used for rehabilitation purposes (Bergeles & Yang, 2013) but with the evolution of technology and their increased ability to process data, they can be used, among others, to help with diagnosis and even surgery (Tangsrivimol et al., 2023).

Robots can have a variety of definitions, like "an automatic device that performs functions normally ascribed to humans or a machine in the form of a human" (Maan Al-Salihi et al., 2022) but for the purposes of this thesis it was used the one from the Robotic Institute of America, that defined it as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or other specialized devices through various programmed motions for the performance of a variety of tasks" (Mattei et al., 2014).

In the healthcare industry, surgical robots have been defined as "extensions of computer systems that allow for programme to interact with humans in a medical setting allowing for greater precision, delicacy and improved capabilities of surgeons while performing procedures"

(Ahmed et al., 2018) and robotic surgery as "surgical procedure or technology that adds a computer technology–enhanced device to the inter- action between a surgeon and a patient during a surgical operation and assumes some degree of control heretofore completely reserved for the surgeon" (Herron et al., 2007).

The first robotic surgery was in 1985, when PUMA 200 was used in neurosurgery to "guide biopsy cannulas under computed tomography (CT) guidance, improving accuracy and reducing procedure time compared with a manually adjustable frame" ((Khanna et al., 2021)). When published in 1988, its success boosted the introduction of robots in the field, but even though neurosurgery was the first specialty to use this type of technology, anatomical limitations led to the higher development in other areas like general surgery and urology (Ahmed et al., 2018) . One successful example of this is the Da Vinci robot from Intuitive Surgical Inc. (Bergeles & Yang, 2013).

2.1.2 State of robots in neurosurgery activity

Currently, surgical robots have not reached a fully autonomous state (Attanasio et al., 2021) being called "co-robots" due to their symbiosis with the human being (Ahmed et al., 2018; Stumpo et al., 2020). Nevertheless, we can classify robotic surgery taking into consideration different criteria such as "working environment, manipulator design, targeted structure and methods or level of autonomy (Ahmed et al., 2018). In terms of autonomy, robots can fit into levels from 0 (no autonomy) to 5 (full autonomy), however the last one has not yet been witnessed (Attanasio et al., 2021).

Level 1 is also known as "robot assistance" where the surgeon receives cognitive or physical support. At level 2, the task autonomy level, the robot can perform a sequence of tasks without the ability to alter them during the procedure, whereas at level 3 the robot has the capability to interpret the surgical situation, plan and perform the procedure, altering the planning if necessary. At both two previous levels, the control switches from the human to the robot. Finally, at fourth level (high autonomy) the robot can "interpret preoperative and intraoperative information, devise a surgical plan, and execute it autonomously, replanning if necessary" (Attanasio et al., 2021) , under the constant supervision of the surgeon. The implementation of this last level may lead to the need to formulate clear regulations.

Neurosurgery is a complex specialty that requires high precision standards and even though there are anatomical constraints and limited maneuverability (Stumpo et al., 2020), robots have

been proved to reduce fatigue (Pangal et al., 2022) ,reduce procedure durations (Stumpo et al., 2020), and increase concentration while improve outcomes (Herron et al., 2007).

Robots can aid surgeons in the different phases of their activity (planning, registration, execution) (Wagner et al., 2021) but also in different types of surgery. In spinal surgery, for example placing screws, in neuro-oncology using frameless stereotactic radiosurgery to treat tumors and in endovascular neurosurgery where several technologies have been tested (Stumpo et al., 2020).

2.1.2.1 Existing technology at the moment

Over the years, many technologies have been tested, used and proven successful for neurosurgery purposes. As mentioned before, the first robot in neurosurgery was called PUMA 200, used to place a biopsy needle in the brain (Ahmed et al., 2018). From that moment on, other types of technologies and robots were implemented in the neurosurgery activity that changed the field, as we can see in Figure 2.1 from *"Robotic Applications in Cranial Neurosurgery-Current and Future"* (Ball et al., 2021).

2.1.3 Perspectives on robotics in neurosurgery activity

Evidence suggests that Robots have not yet reached a state of full autonomy, nevertheless from the literature reviewed it is clear that this is a very dynamic area that is constantly evolving. However, there is a number of authors that anticipate future applications of technology in the different phases of neurosurgery activity. For the sake of this research, we will assume 3 phases, planning, registration, and execution (Wagner et al., 2021).

2.1.3.1 Planning phase

The preoperative state of neurosurgery is a crucial step since "quality, usability, and handling of these images will translate into improvements for the field." (Wagner et al., 2021). To this extent, some advancements foreseen are in image enhancement, automated segmentation, and planning assistance (Wagner et al., 2021).

Machine learning was defined by Arthur Samuel as "the field of study that gives computers the ability to learn without being explicitly programmed"(Mahesh, 2018). In this sense, it can be used to image enhancement of MRIs and CTs in the neurosurgical field. It can be applied to optimize image reconstruction parameters, to do the reconstruction itself, by producing ultimate

Device	Status	Role	Reference
Neuromate	Commercially available	Used in frameless stereotaxis with semiautomated targeting, endoscopy as surgical assistant.	(Ball et al., 2021)
Rosa	Commercially available	Used in frameless stereotaxis with semiautomated targeting, endoscopy as surgical assistant.	(Ball et al., 2021)
Mazor Renaissance	No longer commercially available	Used in frameless stereotaxis with semiautomated targeting.	(Ball et al., 2021)
Stealth Autoguide	Commercially available	Used in frameless stereotaxis with semiautomated targeting,	(Ball et al., 2021)
SurgiScope	Commercially available	Used in frameless stereotaxis with semiautomated targeting,	(Ball et al., 2021)
Corpath GRX Robotic Systems	Commercially available	Tele surgery.	(Ball et al., 2021)
Neuroarm	Not commercially available but used clinically	Tele surgery. Microsurgical movements.	(Ball et al., 2021)
Gamma Knife	Commercially available	Minimally invasive technique used in radiosurgery to treat lesions in the skull, brain, or neck through radiation.	(Régis et al., 2004)

Figure 2.1: Summary of robotics in surgery. *(source: Adapted from Ball, T., González-Martínez, J., Zemmar, A., Sweid, A., Chandra, S., Vansickle, D., Neimat, J. S., Jabbour, P., & Wu, C. (2021). Robotic Applications in Cranial Neurosurgery: Current and Future. Operative Neurosurgery, 21(6), 371–379.)*

image slices from unprocessed data and "provide advanced image processing features such as metal artifact reduction" (Wagner et al., 2021). All of this can be achieved without changing hardware which will simplify its implementation, according to (Wagner et al., 2021).

2.1.3.2 Registration phase

Registration can be defined as "the process by which the frame of reference of preoperative images is aligned to intraoperative anatomy" (Wagner et al., 2021) and technology has been developed in a way to reduce its workload.

Therefore, some systems have been created to reduce radiation, to incorporate depth sensing into medical devices, and to implement "low-field MRI support for registration and registration loss detection", with for example the FDA approved Hyperfine ("uses algorithmic improvements to offset the decreased sensitivity associated with low magnetic field strength") (Wagner et al., 2021).

2.1.3.3 Execution phase

Finally, robotics can have a big role in the operative stage. First, even though full autonomous robots do not exist yet, the existence features already provide the surgeon with a great help.

Augmented reality is also becoming more relevant in the field, being used to surgical navigation improving efficiency and reducing radiation (Wagner et al., 2021). Apart from that, developments in AR can make it possible to create "a unified education plan for future neurosurgeons" (Cannizzaro et al., 2022).

2.1.3.4 Main prospects for the future

There are 3 emerging topics in the neurosurgical activity: AI, remote surgery, and training systems (Zhou et al., 2023).

Firstly, Artificial Intelligence is gaining ground in various industries and robotic surgery is one of them. It can be used as a "precision medicine tool", support neurosurgeons in preoperative tasks by, for example, "developing personalized treatment plans" and due to the ability to process large amounts of data, it can be a tool to improve diagnosis (Tangsrivimol et al., 2023).

Another big prospect is the rise of remote surgeries, through internet technology and robotics development. This would improve outcomes, since these would not be dependent on the surgeon's skills and experience, promoting a higher balance between development and undeveloped

areas (Zhou et al., 2023).

At last, there's a great focus on the training not only of actual surgeons, to deal with the present technology, but also with the education of future doctors. As mentioned in "A virtual reality surgery simulation of cutting and retraction in neurosurgery with force-feedback" surgical training can be defined as "the acquisition of theoretical knowledge complemented with practical observation during surgery and, at a suitably advanced stage, performing the relevant procedures on real patients under appropriate supervision" (Wang et al., 2006). This way, the development of virtual training systems, where AI and machine learning play a huge role by "providing new means of accessing data repositories", will decrease costs of training and decrease the learning curve (Vrontis et al., 2021; Zhou et al., 2023).

2.1.4 Advantages and challenges of robotics in neurosurgical activity

Robots have been a great asset in helping surgeons by overcoming human limitations. These advances enable a better "surgical precision, stability, and dexterity" (Mattei et al., 2014) while also decreasing procedure time and workload, which may increase their success rate and decrease fatigue.

Another big advantage that robots bring is the capability to reach locations otherwise impossible, due to anatomical constraints (Ball et al., 2021).

Overall, we can assume that robotic surgeries are more efficient, what benefits not only the doctor but also the patient. Nevertheless, there are some challenges and limitations raised by the advancements of robotics in the neurosurgical activity. Firstly, on an anatomic level, neurosurgery deals with very fragile tissues and limited space, what, as mentioned before, makes it harder to implement certain robots (Mattei et al., 2014). Secondly, the implementation of new technologies may call for additional training of healthcare professionals as well as renovation of operations rooms and technical maintenance(Ball et al., 2021), which will require time and costs (Khanna et al., 2021). Finally, these new technologies can raise some concerns about their safety (Ball et al., 2021),one example are AI models that may lack the representation of certain backgrounds and ethnicities (Tangsrivimol et al., 2023).

This way, the creation of new regulation must follow the development of technologies if we want it to be and helpful assent to the healthcare industry (Attanasio et al., 2021).

2.2 Robotics in HR

Robots are commonly used to increase efficiency in systems due to their ability to perform consistently repetitive work (Suvarna & Kotalkar, 2019), and even though they can be more implemented or not depending on the type of industry (Suvarna & Kotalkar, 2019) it is predicted that in a near future these systems will be used for service experiences (van Doorn et al., 2017).

The true is there is a gap regarding the impact of these robots in the management of human capital (Krystel Libert et al., 2020) but it is expected that they constitute a new way to manage workers, improving processes and performance, which has its advantages and disadvantages (Suvarna & Kotalkar, 2019; Vrontis et al., 2021).

2.2.1 Managing the implementation of technology

Implementing these new technologies can cause different types of reactions within the organization and on the people who are being managed, and so various theories were created to understand what factors will influence possible behavioral differences.

One of the most known theories is the Diffusion of Innovations Theory, by Everett Rogers. Rogers aims to explain how innovation is adopted by a group of people, considering that "innovation, communication channels, time, and social system are the four key components of the diffusion of innovations" (Sahin, 2006). With this goal in mind, he categorized the social system in terms of innovativeness, what he described as "a relatively-stable, socially-constructed, innovation-dependent characteristic that indicates an individual's willingness to change his or her familiar practices", creating five levels of adopters, "the classifications of members of a social system on the basis of innovativeness" (Sahin, 2006). These categories are:

- Innovators – The first ones to adopt it, they are willing to take risks and usually have stable financial resources
- Early adopters – The second ones to adopt it, usually they have leadership roles and are respected by their peers, open to change but they are more careful about risks than the innovators.
- Early majority – Open to change and innovation but prefer to see the results before adopting it.

- Late majority – This group is more conservative than the previous ones, prefer to adopt the innovation only after it being widely recognized and tested.
- Laggards – The last ones to adopt innovation, they tend to avoid technology until it is necessary to use it.

This way, this theory takes into account "socioeconomic status, personality variables and communication behaviors which usually are positively related to innovativeness" (Sahin, 2006) , making it clear that aspects like complexity and testability influence the decision making.

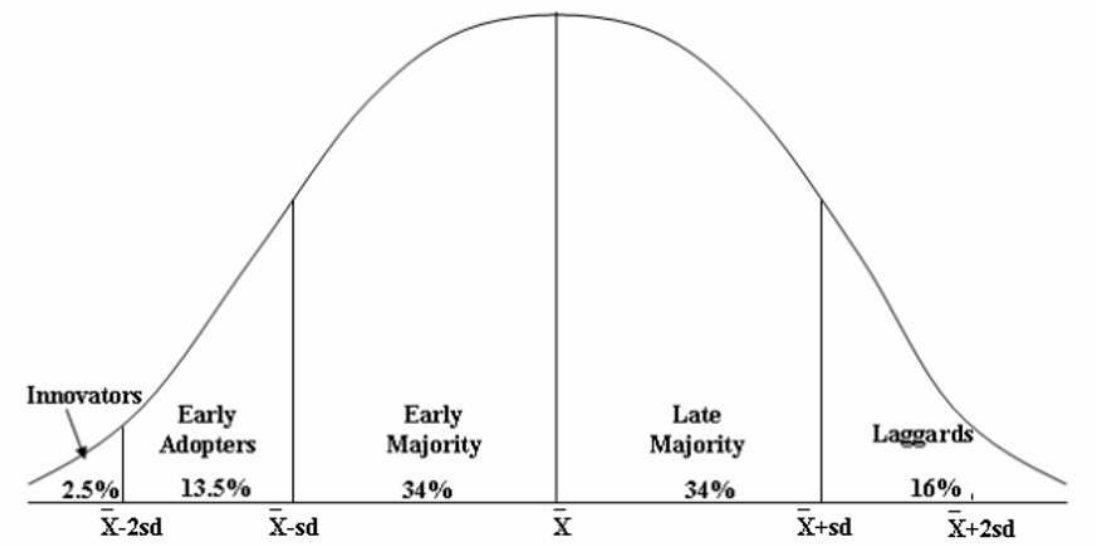

Figure 2.2: Adopter Categorization on the Basis of Innovativeness. *(source: Diffusion of Innovations, fifth edition by Everett M. Rogers. Copyright ©2003 by The Free Press. Reprinted with permission of the Free Press: A Division of Simon & Schuster.)*

Another important theory to keep in mind is the Technology Acceptance Model 2 (TAM2) by Fred Davis and Viswanath Venkatesh. This theory states that the probability of someone adopting an innovation depends on the Perceived Usefulness ("the degree to which a person believes that a particular information technology would enhance his or her job performance" (Chismar & Wiley-Patton, 2003)) and Perceived Ease of Use ("the degree to which a person believes that using a particular innovation would be free of effort" (Chismar & Wiley-Patton, 2003)), adding that there are cognitive factors (job relevance, output quality, result demonstrability, and perceived ease of use) and social factors (subjective norm, image, and voluntariness) influencing the Perceived Usefulness.

At last, the Theory of Reasoned Action (TRA) is also used to describe the behavior of someone specially when faced with change. TRA defines behavioral intention as "the relative

strength of a person's likelihood to perform an anticipated behavior" and states that it is influenced by the attitude towards the behavior, considered the individual assessment, and the subjective norm ("combination of perceived expectations from relevant individuals along with the intention to comply with such expectations") (Otieno et al., 2016).

Having said that, it is important to define strategies to manage the workforce effectively. Studies of various authors have contributed to the creation of different theories that help us to manage change in an organization.

Kurt Lewin created a 3 levels model, based on the belief that human behavior is impacted by individual and social aspects. The 3 levels to create change are "unfreezing, moving and refreezing". This means that the first step is to provoke dissatisfaction, questioning current practices and creating a pro-change environment, with the "realization that the potential benefits of change outweigh the potential negatives associated with the process" (Batras et al., 2014). The second step is "moving", the process of change itself, where actions towards training needed and new roles planning may happen (Batras et al., 2014). At last, happens the "refreezing", where these changes are stabilized within the organizational culture through, for example, creation of policies.

2.2.1.1 Impact of Robotics in Human Resources

As mentioned before, robots can be a great asset in the workplace and "positively affect organizational performance" (Krystel Libert et al., 2020). Robotic systems can perform tasks more accurately and consistently without supervision, if fully autonomous (Mohamed et al., 2022). This will decrease human errors and boredom when performing repetitive tasks, increasing efficiency, and so increasing productivity (Mohamed et al., 2022; Suvarna & Kotalkar, 2019).

Even though the automatization of tasks often raises some concerns about the replacement of work positions with robots, it is most probable that robots only support humans to achieve the best results possible. One example of that is robotic surgery, since currently robots can help surgeons surpass human limitations, but the doctor is still a crucial part of the process (Vrontis et al., 2021). Regardless, this replacement is not predicted in most industries, the job descriptions and responsibilities will probably be altered, what offers employees several learning opportunities (Vrontis et al., 2021). This means not only that the human capital will be able to focus on more challenging matters, but also that automatization will create other types of job,

such as “more technical positions” (Suvarna & Kotalkar, 2019; Vrontis et al., 2021).

This shift of focuses will value highly qualified workers, “backbone of any organization”, reducing the time spent in monotonous tasks and giving opportunities for them to develop new skills (Suvarna & Kotalkar, 2019).

2.2.1.2 Challenges of robotics in Human Resources Management

Despite the several advantages brought by technology, it is important to take into consideration its challenges, in order to find the right balance when implementing.

Even though, some authors defend that job loss will not be that severe and will rather be a switch of responsibilities that will still take some years (Vrontis et al., 2021), others state that the uncertainty created by this is undeniable (Krystel Libert et al., 2020; Qureshi & Syed, 2014). There will be in fact a change in the skills needed and so companies may have to spend time and money in the training of their employees (Krystel Libert et al., 2020). In “Human-Machine Interaction and Human Resource Management Perspective for Collaborative Robotics Implementation and Adoption” stress caused by technological implementations was defined as “technostress” (Krystel Libert et al., 2020) and it can lead to lack of motivation and commitment from the employees or even affect worker’s health (Krystel Libert et al., 2020).

Besides that, the use of robots raises some concerns in terms of security, for example in service providers robots. For instance, “there are issues related to social robots that collect consumers’ facial expressions and try to make inferences about their emotional states, while also collecting biophysical data (e.g., blood pressure, heart rate, hormonal levels, fertility, and menstrual cycles)” (van Doorn et al., 2016).

The biggest challenge is then the way we adapt to these innovations. All of this will induce social changes and so it is important to adopt innovate strategies and invest in the human capital so they can develop the right skills (Suvarna & Kotalkar, 2019; Vrontis et al., 2021).

2.2.2 Impact of robotics in the healthcare workforce

From all the literature reviewed it is undeniable that robotics will have an impact in the healthcare workforce, since they “can transcribe and store information, help doctors and nurses diagnose their patients, and even allow lower-skilled health care workers to treat patients with less over- sight from doctors and other higher-skilled workers” (Qureshi & Syed, 2014).

Robotic systems can also be a great help, since there is a shortage of nurses worldwide that is

expected to get worse with retirement, and their implementation would be a solution to decrease the nurse-to-patient ration, improving patient care (Qureshi & Syed, 2014).

Like in any other industry, the concerns related to job loss also apply to healthcare. While some authors say that even healthcare professionals are not safe with the automation of the workplace (Suvarna & Kotalkar, 2019), others claim that the healthcare industry demands social intelligence and empathy, not acquired by robots, and so these are not jobs at a high risk of replacement (Vrontis et al., 2021).

In "Domo Arigato Mr. Roboto: Emergence of Automated Social Presence in Organizational Frontlines and Customers' Service Experiences", it was developed a framework to analyze the symbiosis between Automated and Human social presence in service providing situations. (van Doorn et al., 2016).

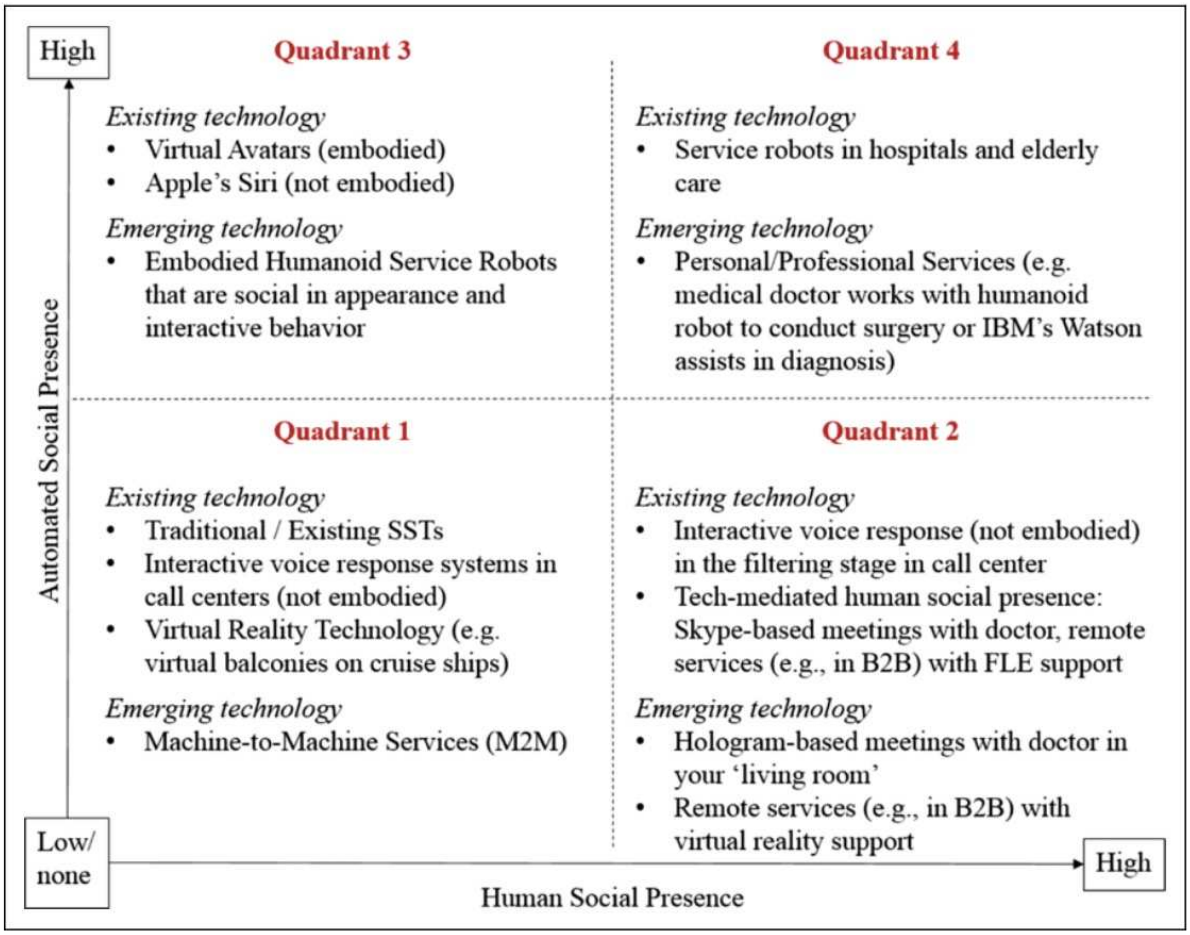

Figure 2.3: Matrix representing different levels of cooperation between human and robots. *(source: van Doorn, J., Mende, M., Noble, S. M., Hulland, J., Ostrom, A. L., Grewal, D., & Petersen, J. A. (2016). Domo Arigato Mr. Roboto: Emergence of Automated Social Presence in Organizational Frontlines and Customers' Service Experiences. Journal of Service Research, 20(1), 43–58.)*

In the framework it is noticeable that healthcare services represent a high "Automated Social

Presence", high "Human Social Presence", which means that it is an area where the strong interaction between human and robots is crucial to obtain the best outcomes possible. In this sense, teams will evolve in every healthcare specialty. For example, the implementation of surgical robots will "require unprecedented levels of collaboration among engineers, surgeons, and healthcare operators to ensure that communication among all actors in the operating theater is improved by the new technology" (Attanasio et al., 2021).

2.2.2.1 Performance management in healthcare

Performance management is the measurement of an employee's performance, with the goal of improving it, through "feedback, coaching and designing strategies to increase effectiveness" (Fried & Fottler, 2018).

Healthcare presents an undeveloped system of performance management, where multiple times goals are not clearly defined and analysis and reporting systems fail (Mettler & Rohner, 2009), but with the raising challenges in healthcare, this constant control of metrics has become increasingly important (Mettler & Rohner, 2009).

For it to be measurable and trackeable it has to be based on data, that are known as performance indicators and can be outcome indicators or process indicators. An outcome indicator reflects the end result or the duration while a process indicator reflects the interim results (van der Geer et al., 2009). Defining these indicators depends on different factors such as task uncertainty, that bears on "specificity of initial situation, specificity of task strategy, predictability of interim results, predictability of total duration, and predictability of end results" (van der Geer et al., 2009). Studies state that teams dealing with high task uncertainty, like in the healthcare industry, should define more process indicators, since "it is impossible to indicate what actions caused outcome variations, making outcomes an invalid basis for adapting task strategies" (van der Geer et al., 2009).

At last, technology adoption can be seen as an opportunity to improve not only performance itself but also the way we manage it, offering new tools to collect, analyze and report the data. This, allied with regulatory changes and increased market dynamics present key drivers for the increasing focus on performance management (Mettler & Rohner, 2009), having to pay more attention to the employees and overall organization's necessities.

2.2.2.2 Education and training of the workforce

With the implementation of technology and the consequent appearance of new techniques a new neurosurgeon's profile may be also appearing within the healthcare industry(Shlobin et al., 2021). More than ever, a balance between technical and non-technical skills has been gaining relevance for the profession (Carpenter & Sundaram, 2017). Skills like flexibility, (Shlobin et al., 2021), team work (Carpenter & Sundaram, 2017) and decision making are being valued(Chen et al., 2020), and even though sometimes they are difficult to assess, it was suggested the creation of task list for preoperative, intraoperative, and postoperative environment, to develop trainees' communication in each (Carpenter & Sundaram, 2017). Nevertheless, creating a complete training plan is not easy and lack of standardized methodologies can increase educational inequalities leading to patient care inequalities (Carpenter & Sundaram, 2017). Some specialties have developed their own original "Standard Operating Practices", like the American Urologic Association that created a framework to train and guide robotic surgeons (Carpenter & Sundaram, 2017). Knowing that a responsible patient care is the main objective, there has been an increased focus on simulators (Chen et al., 2020), testing "web-based training programs" (Chen et al., 2020), that allow trainees more freedom in managing their time, and systems of virtual reality. These systems offer opportunities to interact with an immersive virtual world, where students are able to plan and perform surgeries. Even though these strategies require a higher initial cost, they also offer multiple advantages like evaluating knowledge, decision making and practical skills, being a reusable model and not harming patients (Suri et al., 2016).

2.3 Summary

Keeping this in mind, I focused on Robotics in Neurosurgery (present and future) and Robotics in HR as main topics of the interviews, where organizational structure, task distribution and training needed where identified as subtopics, since they are micro aspects that influence the way we manage HR in healthcare.

Topic	Subtopic	Literature
Robotics in Neurosurgery	Present of neurosurgery	Robots can be classified into levels from 0 to 5 in terms of autonomy, and now there no fully autonomous robot in neurosurgery, only working in symbiosis with the surgeon. Some already used technologies are the Neuromate, Robot arms, ROSA, Gamma Knife, among others.
	Future of neurosurgery	The plan is that in the future robots can fully help surgeons with the 3 phases of surgery (planning, registration, and execution), by revolutionizing the area with the 3 main prospects: AI, remote surgeries, and new training systems.
Robotics in HR	Managing HR and technology	There are theories that can explain behavioral divergences in organizations when faced with change, like the implementation of robotic systems, such as: Diffusion of Innovations Theory, Technology Acceptance Model and Theory of Reasoned Action. To know how to deal with this, various models were defined, like the Kurt Lewin's one, that focuses the creation of an environment conductive to change, through changes in organizational structure and task distribution, for example.
		Technology can bring a lot of benefits to the workplace, improving performance by increasing efficiency and decreasing human errors and limitations, while reducing repetitive and more boring tasks, increasing learning opportunities to more challenging roles. On the other hand, it also increases concerns of job loss and security.
	HR in Healthcare	Performance Management is an important but undeveloped subject in healthcare. It is crucial to define clear goals and process indicators, combining it with effective data analysis and reporting systems. Technology can be a great help with it but also be the motivation for this stricter tracking to happen.
		With all the mentioned innovations, the profile of future neurosurgeons will change a lot, in terms of skills and of courses the training needed. New ways of teaching seem to revolutionize the education, through methods like Virtual/Augmented reality.

Figure 2.4: Literature Review Scheme

Chapter 3

Methodology

3.1 Research Approach

As already mentioned, the main goal of this dissertation is to “understand how technology will impact these teams and their management”, with special focuses on the organizational structure, task distribution and training needed. Keeping this goal in mind, the methodology chosen was to conduct interviews, carrying out a qualitative approach.

Qualitative research was defined to develop ”concepts which help us to understand social phenomena in natural (rather than experimental) settings, giving due emphasis to the meanings, experiences, and views of all the participants” (Patricia Huston & MargoRowan, 1998). This type of research is commonly used in healthcare since it is a good way to capture participants experiences and perceptions (Gill et al., 2008; Huston & Rowan, 1998; Veluswamy et al., 2013).

3.2 Interview development

3.2.1 Selection of participants

When conducting interviews as research method, it is extremely important to understand who our sample should include, so recruitment of participants is a crucial step.

In this case, the interviewees must be contextualized with the healthcare industry, in specific with the neurosurgical activity. In this regard, it was applied a purposive sampling (Adeoye-Olatunde & Olenik, 2021), since the participants have to meet the criteria of “being a neurosurgeon”.

Besides that, it is relevant to gather information and perspectives from around the world since the contexts of robotics may vary from country to country. Thus, a network selection was used, by first approaching the first neurosurgeon, who then recommended us some more, meeting the criteria of multiculturalism (Demarrais & Lapan, 2004).

At last, one aspect to note is the dimension of the sample in a qualitative study. In this type of research there is always some uncertainty regarding the right number of participants. To overcome this, I tried formulate detailed in-depth interviews, to tackle every subject (Demarrais & Lapan, 2004). For these purposes, 21 neurosurgeons were approached by email or Linkedin (Appendix I), of which 6 were interviewed based on their availability and interest in participating.

3.2.2 Building the script

There are different types of structure for interviews, for this case in specific it was built a semi-structured one. This kind of format is particularly useful since it provides the chance to follow a script while also adding some follow-up questions, to explore the participants' point of view in a more in-depth way (Adeoye-Olatunde & Olenik, 2021; Naz et al., 2022; Rowley, 2012).

Before designing the script two topics were selected as main pillars of this dissertation, "robotics in neurosurgery activity" and "robotics in Human Resources". Keeping this in mind, it was possible to build a framework to work as a guide to the interview, focused on the topics and subtopics defined. This was followed by the selection of main theories from the literature analyzed (Maxwell, 2008), since this was the main source of information. Hereby, it was possible not only to critically compare the participants answers with the literature, but also to make sure the answers were comparable between all the participants (Naz et al., 2022). These two aspects combined facilitated the acquisition of coherent and structured data, what led to a clearer conclusion.

While forming the questions it was kept in mind the importance of not influencing the participant's answers. For this, questions were formed in a neutral way, avoiding a close-ended style (Chenail, 2011; Gill et al., 2008). At last, to ensure participants were at the same level in terms of context, videos and written explanations were shown, when their opinion about certain example of technology was asked (Jorge et al., 2008).

	country	Years of experience	Sector	Experience with technology
NS 1	UK	7	Public	Yes
NS 2	PT	11	Private	Yes
NS 3	IT	14	Public	Yes
NS 4	GER	7	Public	Yes
NS5	IT	17	Private	Yes
NS6	PT	7	Both	Yes

Figure 3.1: Participants' information

3.3 Conducting the interview

As mentioned before, the interviews were conducted in a semi-structured way, what allowed the possibility to explore more the participants perspective and understand their experience. This means that sometimes, some strategies were used to develop more the conversation, just like probing. Probing is a way to ensure clarity in the interviews, if, for example, a topic is not covered by the participant or they give an answer that does not align with the questions, a way to do this was for example repeat the question or reformulate it (C. Harrel & A. Bradley, 2009).

All participants were informed about the anonymous character of the interview, and asked if they were comfortable with it being recorded, to help with the outputs analysis. Each interview took approximately 50 minutes, from 6 interviews, 2 of them were conducted in Portuguese and 4 in English.

Firstly, two pilot interviews were done (one in English and one in Portuguese), what made it possible to make some adjustments in content and structure, making sure that questions were relevant, clear, and not repetitive (Gill et al., 2008; Naz et al., 2022). These two pilot interviews were included in the data analysis since they provided pertinent information to the study.

Audios were carefully transcribed after each interview, taking into consideration cautious translation when needed. This allowed a constant adaptation of my posture during the interview, avoiding nodding my head or agreeing with answers, to ensure the most neutral space possible.

3.4 Data Analysis

When conducting a study, it is a crucial step to define an appropriate method of analysis, that matches the characteristics of the research and allows us to take the right conclusions. In this case, and since this was an exploratory study into a relatively unexplored field a grounded theory approach and qualitative methodology was chosen under an interpretative epistemology.

This approach means to identify topics and themes from collected evidence rather than a previously conceptualized theoretical structure. This was done by organizing and conducting a clear analysis of interviews' content in a free manner and later establish categories and labels, making it easier to find patterns and differences between the participants (Lacey & Luff, 2009). Adding up to that, the fact that it is a thematic analysis offered a more flexible line of action, which maintained the subjectivity that is so relevant for this case, without the quantitative side, that may be present in a content analysis.

It is important to note that both inductive and deductive approaches were used. On the one hand, before the interviews, literature was analyzed and taken into consideration when building the script so then it would be possible to compare it with the answers. On the other, when building the framework for the analysis, I assumed a bottom-up strategy, since the themes were based on the observations (C. Harrel & A. Bradley, 2009).

At last, efforts to ensure the reliability and validity of the study were made. Regarding reliability strategies like carefully explaining the approach adopted and the process of analysis were used. When talking about validity, measures like analysis different sources, like interviews and document analysis, were taken.

Interviews were recorded and transcribed, and in this process, the main topics were noticed. The following steps were undertaken: 1. all the identifiable aspects were removed, and numbers were attributed to each participant; 2., after being familiarized with the data, the coding process started. Developing a code for research implied, after identifying the main themes, searching for sub-themes across all the observations and properly signalize them. In this case, a color method was used, and substantives and attribute codes were defined. Attribute codes represent the participant's characteristics and can be applied to the entire study, so I used "country", "years of experience counting with training" and "sector". In other respects, substantive codes reflect the participants answers (C. Harrel & A. Bradley, 2009), and so different codes were defined throughout the study for each framework.

After this, the charting took place, organizing the data in the frameworks, where each line represents a participant and each column a code or theme. In this case, three frameworks were created, one for each research question. This decision was taken mainly due to the quantity of data, that would complicate the analysis, and so three frameworks would provide a more focused and clear interpretation of results. All of this was keeping in mind that adopting this approach comes with limitations, and so and extra effort was made to not miss connections between data.

In the following section, the results of the analysis are presented.

Chapter 4

Results

4.1 Present of Neurosurgery

This section aims to analyze the current situation of technology in the neurosurgical activity, taking into consideration the two first questions of the interview.

As attribute codes we have “country”, “years of experience” counting with training, and “sector”. As substantive codes we have “current technology” implemented at each hospital, “familiarity with Gamma Knife”, “Advantages of Gamma Knife” and “Disadvantages of Gamma Knife”. If a certain space is filled with a “-” it means the topic was not mentioned by that participant.

As we can see in the chart below, the navigation system is the most used one (by 5 out of 6 surgeons), and some new technologies like recent robots and AI are being implemented in two hospitals.

Regarding Gamma Knife, it was considered that every surgeon was familiarized with it (even if they did not use it before) if they had heard about it and knew how it works. Even giving different answers, when it came to advantages all of them recognized the same ones, related to it being a noninvasive technique without anesthesia, enabling accessibility to challenging areas, increasing effectiveness and safety. Participants 2,3 and 6 showed concerns related to post surgery effects as disadvantages, and participant 3 even mentioned effectiveness as a possible advantage and disadvantage, since the time for the procedure to present its effects can be longer. At last, Participant 1 alerted to the use of radiation, stating that “because it can sound more appealing to the doctors, and patients that may want to avoid the operation and the risks, it can be overused” and that it is necessary to have “proper consultation of the patient or proper

multidisciplinary discussion of the case".

	Country	Years of experience	Sector	Current technology	Familiarity with Gamma Knife	Advantages of Gamma Knife	Disadvantages of Gamma Knife
NS 1	UK	7	Public	Navigation system, robots arms for implantation of cables or screw positioning	Yes	Patient's safety, increase effectiveness, noninvasive procedure, access to challenging areas	Radiation, tendency to overuse in not adequate situations
NS 2	PT	11	Private	Navigation system	Yes	Noninvasive procedure, access to challenging areas	Only deactivates da lesion, inflammatory reaction
NS 3	IT	14	Public	System for epilepsy surgery, implementing for stereotactic biopsies	Yes	Lack of anesthesia, Patient's safety, increase effectiveness, access to challenging areas	Lack of effectiveness, time needed to present effects.
NS 4	GER	7	Public	Navigation system, implementing AI for planning surgery	Yes	Lack of anesthesia	-
NS5	IT	17	Private	Navigation System	Yes	Increase precision, help with planning	-
NS6	PT	7	Both	Navigation System, robots to train skills	Yes	Noninvasive procedure	Possibility of dysplasia

Figure 4.1: Table of results for questions 1 and 2

4.2 Future of Neurosurgery

In this section, the perception of surgeons about the future of their activity is going to be presented, taking into consideration the questions about artificial intelligence and remote surgery.

For this purpose, the attribute codes remained the same and as substantive codes used were

"Perception of AI", "Uses of AI", "Concerns about AI", "Next steps towards AI", "Perception of RS", "Concerns about RS ", "Advantages of RS". Once again, if a certain space is filled with a "-" it means the topic was not mentioned by that participant.

For the codes related to the perception of surgeons about AI and remote surgery, their answers were interpreted into "positive", "moderate" or "negative".

	Country	Years of experience	Sector	Perception of AI	Uses of AI	Concerns about AI	Next steps towards AI	Perception of RS	Concerns about RS	Advantages of RS
NS 1	UK	7	Public	Positive	Improve diagnosis, enhanced imaging, operation planning	Lack of knowledge to create regulation	Trials to gradually reevaluate	Moderate	Lack of in person care, lack of tactile feeling	Access places without high quality of care
NS 2	PT	11	Private	Positive	Help with decision making, Better comparative studies	AI may not know which technique works better for a specific patient	Use self learning features to evolve	Moderate	Lack of know how without tech, Technology failing and not having someone to perform the surgery in person	-
NS 3	IT	14	Public	Positive	Help with decision making, develop guideline, enhanced imaging	Surgeon's lack of control, lack of clarity regarding responsibility	Create regulation	Moderate	Technology failing and not having someone to perform the surgery in person, difficulty with managing after surgery complications	-
NS 4	GER	7	Public	Positive	Radiology department, logistics, intraoperative control	lack of clarity regarding responsibility, lack of awareness about the environment	-	Moderate	Difficulty with managing complications, Technology failing and not having someone to perform the surgery in person	Access places without high quality of care
NS5	IT	17	Private	Positive	Radiology and pathology department, Diagnosis, Planning surgeries	-	Discussions within scientific societies	Moderate	Technical problems, lack of in person care	Access places without high quality of care
NS6	PT	7	Both	Positive	Mainly pre operative environment, guiding the patient, helping with diagnosis	AI may not know which technique works better for a specific patient, lack of knowledge for an emergencie	-	Positive	-	Useful for training purposes, learning new techniques without going abroad

Figure 4.2: Table of results for questions 3 and 4

When asked about the implementation of AI in healthcare all of them showed a positive perspective, participant 2 and 3 even considered it a "method of inevitability" and "a big promise for the future" respectively. All of them see this technology being used mostly in the

pre operation environment, helping to plan the surgery, and improving imaging. Adding up to that, participant 2 mentioned that AI can be useful "establishing better comparative studies" and participant 1 and 4 suggested it could be used in some more straightforward procedures like stereotactic navigation and spine surgery , "it will have less problems with planning with AI and executing them with robotic arms".

Regarding concerns the most mentioned ones were lack of regulation and knowledge to create it and lack of control from the doctor, what can cause some issues with responsibility. Participant 2 presented a case as example, where there are multiple ways to perform a surgery and AI still does not have the ability to know which one is better, depending on the patient. Participant 3 even mentioned that he is already working on regulation, whereas participant 1 believes that it is necessary to do trials and continuously reevaluate. Participant 2 believes that AI can improve itself, with self-learning features.

When talking about remote surgery, all of them showed a moderate perspective, which means that they might see it happen but showed more concerns. Even though surgeons 1,4 and 5 agreed that RS might be a great asset when it comes to places without quality of healthcare, various concerns were raised. The lack of in person control and care was mentioned by most of them, and participant 1 stated that "technology really has to advance" to provide that tactile feeling that is so important in this field. The participants also manifested their concerns since it is possible that technology fails and said that there must exist an alternative to this possibility, in participant 2's words "it is important to have a surgeon nearby". Participant 4 said that "spine is probably easier if you have a robot that can perform that, that would be closer in the future, but intracranial surgery is too difficult". At last, Participant 6 mentioned it could be used as a way of training, to learn new skills from doctors abroad.

4.3 Influence of technology in the workforce

In this section, it is going to be explored the impact of technology in Human resources, comparing the current state of hospitals and the perception about how it might change. For this, the questions about organizational structure, task distribution and capacity building will be taken into consideration.

This way, the substantive codes defined were Sub specialized staff, Current multidisciplinary, Changes in ST, Perception on task shifting, tracked data, Influence on motivation, Challenges,

Capacity building received, Future capacity building. Once again, if a certain space is filled with a "-" it means the topic was not mentioned by that participant.

To understand each hospital's reality and context, the surgeons were asked about their current organizational structure and how they worked within the neurosurgical department. All of them work with some type of sub specialization within the surgical team, Participant 5 even mentioned that he believes sub specialization is the right way, if enough professionals.

Regarding multidisciplinary, all participants except number 4 work daily with technicians or engineers, either in person or remotely. For participant 4 this reality only happens if there's a specific problem, what they consider a limitation, "because you never use it to the maximum, and we do not receive feedback to improve and progress faster".

As for future changes in surgical teams, participants 1, 3 and 6 defended that most probably it won't happen. Doctor 1 said that maybe in the future technicians "can start repairing things remotely" but until then, they will have to come in if there's a problem, such as they do now. Adding up to that, P1 also believes that change is more of a "political decision" depending more on financial aspects rather than how technology will evolve. Participant 3 stated that "technology will be present together with the human being, but not replace them", but they also mentioned that an increase of the technical personnel might be a possibility. Overall they agreed that for now it is important to maintain a full team, nevertheless in Participant's 2 words "It is possible that one day we only need a surgeon operating remotely, one near the patient and one anesthesiologist".

When talking about task shifting, most of them talked about robots helping doctors with certain tasks, as we can see in the chart, but participant 4 went further to talk about how they can help healthcare professionals outside of the OR. P4 raised the possibility of using robots for everyday life tasks such as "distribution medication", and AI for bureaucracies like "take the data and gives us a letter of discharge" or even "operational planning and optimization", scheduling procedures. In their opinion this would "reduce time consuming tasks for the nurses and reduce errors due to tiredness" and make it able for all to "focus on more important aspects". About data tracking, Participant 2 and 5 were aware of it, and even though P2 mentioned that the hospital was able to decrease to 0% the review of wrongly positioned screws, they also say that "they are working to improve it", since there's not differentiation in the techniques for each surgery. As for participant 3 and 4, tracking data in the medical environment is not easy and may demonstrate some subjectivity, P4 even said that "the success rate of very good surgeons is

probably lower because it depends on the challenge you face".

In regard to the impact on motivation, different opinions were exposed. While P3, P4 and P5 believe that it would have a positive impact, since it will increase positive results, P1 believes that surgeons must already be motivated individuals and these changes would not have any effect on it. On the other hand, P2 believes that implementing new technology requires adaptability and healthcare professionals are already under a lot of pressure, so it might have a negative effect for some.

Various challenges were mentioned, from cost to social and technical issues, as we can observe in the chart bellow. All of these are important to take into account in this research, and so these aspects will be further analyzed in the next chapter. Finally, in capacity building we are presented with different contexts. While in P1's hospital only few surgeons received training to work with technologies, P2 and P4 referred to a reality where it depended on each individual's willingness to learn. This way, as expected, we can see that their opinion about the future capacity building is highly influenced by their present context, as for example P1 talked about the importance of sub specialization of nursing staff and anesthesiologists and others mention the need for an increase in workshops.

Furthermore, three of them suggested that young doctors should train more on models than on cadavers or patients. At last, P2 said that it is important that medical students have access to information about these new technologies with elective courses at university and P4 suggested that augmented reality can help us creating scenarios, where students are "completely emerged and solve a case", since he believes that being able to interpret and take action rather than just memorizing information will be characteristics of the "doctor of the future".

	Country	Years of experience	Sector	Subspecialized staff	Current multidisciplinary	Changes in ST	Perception on task shifting	Tracked data	Influence on motivation	Challenges	Capacity building received	Future capacity building
NS 1	UK	7	Public	Only surgeons	Technician available by phone, in person if previously booked.	No	Easier screw positioning and electrodes or chants implantation	-	No	Cost, social conditions	1 or 2 people get special training and these are the ones who perform robotic surgery	Subspecialization for nurses and anesthesiologists, models for trainees to train on instead of cadavers
NS 2	PT	11	Private	Surgeons, nurses and anestheseologists	Biomedical engineers present in the OR	Yes	Symbiosis where robots suggest steps and surgeon validates	Yes, but needs to be improved	Yes, negative way	Resistance from professionals, reduce productivity during implementation, insurance, emotional availability	Elective workshops	Regular touchpoints between doctors and engineers, elective courses for medical students
NS 3	IT	14	Public	Yes, surgeons and nurses	Technicians always in the OR, engineers present during the implementation phase	No	Robots performing repetitive tasks, engineers working alongside with surgeons	No	Yes, positive way	Technical issues, protocol development	Presentations by the companies	Simulations in models, start training trainees and students from a early stage
NS 4	GER	7	Public	Only nurses	No	Yes	Shift in low profile jobs, AI in bureaucracies	No	If so, in a positive way	Responsibility, human connection,	Self learning, Workshops from companies	More workshops, creation of structures to train on, create scenarios with AR
NS5	IT	17	Private	Yes, but they work with non-subspecialized too	Engineers in not standard cases	Yes	Engineers guiding the more practical part	Yes	Yes, positive way	Ethical problems	-	Simulations, courses about AI, robotic surgery, more practical initiatives
NS6	PT	7	Both	Anesthesiologists specific for neuro, nurses general for OR	Engineers in the planning phase, but also in the OR for some type of surgeries	No	-	Yes	Yes, negative way	Economic conditions (from public hospitals and from patients in private ones)	Elective workshops	Using AR, mandatory courses about Biomedical Engineering

Figure 4.3: Table of results for questions 5,6, 7,8,9,10,11,12,13,14,15 and 16

Chapter 5

Discussion

This section discusses main results, advances further hypotheses and avenues of future work and presents the limitations of the current thesis.

5.1 What type of technologies are used at the moment and how are they implemented within the surgical teams?

Before looking into the future, it is important to understand the present context of surgical teams and some differences in their realities were noticed. The navigation system seems to be the most used one, mentioned by most surgeons. Even though literature considers neurosurgery one of the most challenging areas for technological implementation, it already plays a huge role in the activity, since the navigation system can be used to plan but also during the surgery. Besides that, Gamma Knife technology was also familiar to all the participants. In fact, we can see that the P2 and P5's hospitals seem to be the less developed ones in this matter, having only the navigation system. Nevertheless, these 2 doctors seemed to be very enthusiastic about technology, what makes me think that the theories presented in chapter 2 might not explain fully the implementation of technology.

Throughout the interview, Surgeon 2 reflected about the state of the healthcare industry in Portugal, stating that "healthcare professionals are already under a lot of pressure and bureaucratic burden". This may be one of the reasons for what seems to be a lack of investment in robotics. Besides that, lately, the healthcare industry in Portugal has been characterized by many scandals, such as possible abuse of influence by the government and strikes. Lastly, Portugal faces a serious political crisis and financial problems. All of this leads me to think that the

healthcare public system and private hospitals management do not consider technology acquisition and development a priority. On the other hand, despite all of participants having mentioned the strictness of the profession, other countries seem to invest more in new technologies, since they mentioned implementation of new systems and even AI. All of this indicates that surgeons are aware of the new possibilities in robotics even if they are not implemented, which may tell us that it is more of a political and financial decision, confirming participant one's perspective, already presented in chapter 4.

Regarding the way teams work alongside technology it is important to reflect about sub specialization and multidisciplinarity. As we can see in the chart, all of them work with some kind of specialization, but only H2's whole surgical team is. As mentioned by P1 general doctors cost less, and so the fact H2 is a private hospital might indicate a higher budget and so the possibility to work with a bigger and sub specialized team. Some authors say that the implementation of technology would enable employees to focus only on specific parts of their job description (Vrontis et al., 2021), and so these findings are particularly interesting since it is noticeable that one of the hospitals with less technology is also the one with more specializations, raising some questions about if technology and specialization in medicine can be related aspects or not.

In respect to multidisciplinary, we cannot distinguish a clear pattern within the sector type or even the country. Whereas P4 doesn't work with technicians or engineers, all the others cooperate with them, in person or via phone. Overall, the answers confirm that at the moment, neurosurgery is an area with high "Human Social Presence" and a tendency to increase "Automated Social Presence"(Attanasio et al., 2021).

Besides the uses of technology, it is important to note the state of the neurosurgical activity overall. When asked about metrics like success rate and productivity, only half of the doctors said that it is a topic for them. Even these stated that it was more important for management than for them and it should be improved. P6 even said that it is hard to define success after a surgery, since it is very subjective. This confirms literature, that explained how undeveloped information systems for healthcare were (Mettler & Rohner, 2009).

5.2 What are the main prospects for changes in technology and how are they believed to shape the teams?

Regarding their perspective about the future there are not so noticeable differences between them, when it comes to country, sector or even years of experience, since all of them have similar perceptions about concerns and uses of AI and RS. This makes me believe that, as these are still not implemented, their opinion is more based on literature, and it is difficult to distinguish how it would work in different contexts. Having this into consideration, it is fundamental to develop further research, to study how new systems should be implemented, depending on different political, social, and financial situations.

Nevertheless, some logistics points for AI were added, in which robots would help in bureaucracies and with surgery scheduling. When reflecting about remote surgery, doctors showed some uncertainty. For both, doctors raised more concerns than the literature, demonstrating the contrast between theoretical knowledge (more present in literature) and practical work. This shows that, even though they are aware of new tendencies and open to try them out, they are still not 100% confident that it will work in a hands-on experience.

There was no clear behavioral difference within the surgeons, what makes it not appropriate to apply Roger's Diffusion of Innovations theory, but it was clear that the opinions were mainly based on perceived usefulness and perceived ease of use (TAM2).

All aspects above are especially interesting to analyze and relate to the answers regarding changes in surgical teams. P4 agrees that teams will have to change, which is not surprising considering he does not work in specialized or multidisciplinary teams. Nevertheless, P2 is an example of the exact opposite who still believes that these teams should evolve. This shows us that, constant reevaluation is important to make sure teams are performing at their best. What was surprising was the fact that even though all of them have positive and moderate opinions about AI and RS, not all believe that surgical teams will change. P1, P3 and P6 believe that these changes are not likely to happen, but P3 says that an increase of people able to work with machines will be needed. This makes me think that there is still some ambiguity about the way task distribution will change and create and agile workflow. Since answers seem to reflect the Technology Acceptance Model 2 and the uses for technology seem to be based on theoretical knowledge from literature, I believe that this lack of clarity may related to a low "Perceived Usefulness", due to lack of result demonstrability.

Despite the belief in changes in teams or not, job loss is not a concern present in our observations, since they envision a task distribution system where surgeons, robots and engineers/technicians will be cooperating. Nonetheless, P4 brought up a possible shifting in low profile jobs, similar to "Improving Efficiency and Effectiveness of Robotic Process Automation in Human Resource Management" (Mohamed et al., 2022), which might be an attention point for management.

Finally, it is important to note that this is a complex subject to study, since we are dealing with very different contexts and healthcare systems, and even within the same sector (private or public) their management and influence might differ from country to country, what makes it harder to take conclusions. Equality between countries will not be reached but, from a specific point of view, this can work as an opportunity for the development of technologies like remote surgery, where more developed countries can support less developed ones. Overall, it seems that all doctors believe in the implementation of new technologies like AI and RS if they are proved to be useful. There is no consensus about change in tasks and surgical teams yet, maybe because those aspects will vary a lot according to the hospital, since they are not all at the same starting point.

5.3 How will these teams be prepared for the future medical workplace?

Even though interviewees seemed open to the use of technology, they also expressed that some extra work would be necessary to make sure teams were ready for these changes. When asked about challenges that technology can bring to the profession, participants mentioned similar aspects to the concerns they referred in some of the previous answers, such as technical issues, responsibility, and lack of human connection. Nevertheless, they also went further and so it is worth mentioning problems like lack of insurance support and protocol development. This confirms that for the industry to evolve, a whole support system has too, since it is a codependent cycle. Furthermore, the fact that the Portuguese and Italian doctor suggested these challenges, might indicate that healthcare systems in these countries might not be so efficient as in Germany or the UK. Only Portuguese doctors said that technology might have a negative impact on motivation, and even though P4, working in Germany, also mentioned the possible burn out of healthcare professionals, he defended that technology can be a tool to improve this

aspect rather than worsen it. Once again, discrepancies within countries are obvious and may be reflecting the social factors considered in TAM2.

Besides that, the education and training of current and future surgeons is a big topic to take into consideration. Only P6 mentioned the use of robots to train specific skills but it was surprising to notice that even though there is a moderate implementation of technology in the workflow, there were not many initiatives supported by the hospitals, being most of them elective. Apart from that, it was noticed a certain inequality in terms of training, confirming one of the concerns presented in the literature reviewed, what leads to inequalities in patient care.

P4 mentioned the "doctor of the future" and the increased need to know how to interpret situations, demonstrating some concern about the development of "technical skills" (Carpenter & Sundaram, 2017). It was consensual that education must evolve, including more synergies between surgeons and biomedical engineers but also more simulations.

Taking all of this into account, there's still a long road to make, technology must evolve, and organizational structures have to adapt to it, but above all, subjects like training and responsibility have to be well clarified, so neurosurgeons are able to perform their job in the best way, offering patients the best solutions.

5.4 Limitations and Future work

First, it is important to acknowledge the fact that research bias is impossible to fully eliminate, since as literature defines it "Bias refers to ways in which data collection or analysis are distorted by the researcher's theory, values, or preconceptions" (Maxwell,2008), and so citations were included to try to minimize those effects.

Moreover, as already noted, only 6 interviews were conducted due to lack of response and limited time, and even though there is not a defined number of observations to gather in qualitative research, I believe that some more would have added value to the study, in a way for the answers to converge more. This way I believe that it would be important to carry out more detailed research on each country and sector, since it could be easier to reach more respondents, but it would also allow the construction of more solid and adapted strategies and action plans.

Additionally, the sampling strategy used to invite participants was the "network sampling", this means that participants were suggested by other participants. Apart from that, even though an effort was made to reach people from different backgrounds, the contact method and avail-

ability from neurosurgeons also narrows the possibilities. Both, contribute for the reduction of randomness in the study and for the risk of overrepresentation. This way, I think it could be interesting to interview nurses and engineers, among others, to build a more consolidated perspective and even develop a plan for each job.

Even though I believe this study is reliable, I recognize that its validity might be affected by the lack of feedback from respondents, since there's limited time for the research, and by the fact that there is only one researcher conducting the interviews. Besides that, language barriers are also worth mentioning, since they can constitute some limitations for the case. These effects could be reduced if further research is conducted by an international team.

At last, it was also pointed out the lack of awareness for data that surgeons had, and even though neurosurgery can be subjective I think it would be valuable to inquire about the possibility of creating more complex data management systems, cooperating alongside hospital management departments and neurosurgeons.

Chapter 6

Implications and Recommendations

The Kurt Lewin 3 level model is widely used to manage organizational change, making it an appropriate way to explore recommendations in this study. As already mentioned, the 3 levels are unfreezing, moving and refreezing.

After the unfreezing phase, it is time to think about what strategies can be implemented in terms of organizational structure and training needed so then, in the refreezing state these are stabilized, giving special focus to the fully incorporation of these changes into the culture. This way, in the following sections recommendations regarding training needed, task shifting and organizational structure.

6.1 Education and Capacity building

Training and education is a crucial step to manage change, and it should be present in every level of the model. It is important to use it to build trust in change, creating a pro change environment, but also during and after the actual change, to create a dynamic and enriching workplace. During the unfreezing phase, it is important to know how to motivate people. Keeping in mind their answers, doctors seem to be more willing to use technology when it is useful and easy to use (TAM2), and so training initiatives play a huge role in that. Even though, in some cases only a few surgeons are prepared to use determined devices, it seems that in the future all neurosurgeons should be capable of it. For this to happen, hospitals could create a list of skills that healthcare professionals should develop and offer touchpoints for them to get information and trained. Obviously, these training initiatives cannot negatively impact working schedules and so it should be organized by:

- Defining a mandatory number of hours or initiatives professionals have to attend;
- Presenting a timeline over the year, offering various touchpoints, so people could plan when to go;
- Creating a "skills lab" where healthcare professionals could go and train on models when they are free;
- Defining numeric goals for each skill.

Moreover, all these skills should be measurable, and a "planned vs achieved" system should be implemented with this strategy, so doctors could monitor themselves and understand where to improve. I believe this would also work as a motivation strategy, even for those who do not adapt so easily to changes, since it offers a good balance between flexibility and support given by the hospital, and a possibility to see their evolution.

Apart from that it is essential to also focus of the education of medical students, requiring the inclusion of education national systems. It is urgent to deliver education on a practical approach, focusing not only on knowledge but also on skills. For this I suggest the creation of a long-term vision for the healthcare industry, to understand the characteristics needed in future healthcare professionals. After that, it should be easier to develop a top-down plan on how to achieve that.

6.2 Task shifting

The nearest and more easily predicted future, seems to be the creation of a cooperative workplace between robots, engineers and technicians and neurosurgeons, what goes accordingly to the literature reviewed, characterizing the healthcare industry as an area where both human and robot interaction are high.

In my opinion, a robotization of the neurosurgery activity won't lead to a massive job loss. As I see it, technology will be a great asset in taking some pressure of healthcare professionals, especially in such demanding specialty, allowing nurses and surgeons to focus on more important aspects of the job, what will reduce the overwork conditions they are under now and improve the patient care.

For all of this, planning of new roles should start in the moving phase. Performance management is an undeveloped subject in healthcare, data analysis and report systems are not always in place what might difficult decisions about how to manage this type of change. Creating

a workflow for tracking of process indicators could be a useful way to look at clinical data in a more objective way, making it easier to know in which tasks technology could be an asset. All of this should be monitored in the refreezing phase.

Moreover, in the refreezing phase, protocols must be developed to incorporate new devices in tasks. Participant 4 presented two scenarios and from my point of view a combination of the two should be adopted. This would mean that there's a centralized organ who develops more general guidelines that should be used by every hospital. Adding up to that, these organs would also give detailed information on how these protocols could be adapted so they match the local reality better.

6.3 Organizational Structure

As observed the organizational structure can vary from hospital to hospital, and some structures may not be capitalized to help doctors perform and improve. This way, the prediction is that these structures will evolve, including engineers and technicians in the pre, intra and post operative environment, since we can see the future of some in the present of others.

It is difficult to recommend a concrete action plan, since we are dealing with different systems and governments and so we must be careful so we do not fall into a too simplistic suggestion, that may encounter many gaps when implemented.

Organizational structure is a crucial aspect for any work environment, highly linked with results, tasks and even the way training should be delivered. At a hospital level structure analysis should be conducted during the moving phase together with task allocation analysis, searching for inefficiencies that could be solved by technology. Nevertheless, this is not a topic that can be solved only at local level, requiring the optimization of synergies between various organs.

Every country included in this research has both centralized and decentralized systems for allocation of doctors, this means that when medical students graduate, they are allocated by a national system, but there are situations where doctors can apply directly for a job. This may not happen for every country or sector, but since there are no observations of the latter case, all the recommendations will be made keeping in mind the first one and knowing that they must be adapted to each context.

It is extremely important to hold conversations about these matters at a government level, including carefully in the state budget, not only investments in technology but also the costs of

structures alteration that can happen from it.

At last, it was commented the lack of support from insurance companies, what leads to patients not wanting to pay for new technologies. This would mean that hospitals would be investing in new devices and in specialized professionals “vainly”. Once again it is noticeable that this is a complex topic to optimize since there are a lot of variables to consider. From my perspective insurance companies should:

- Make sure they have responsible employees for market research, to keep up to date with new trends and technology.
- Establish clear conditions for when to cover new technologies and constant adapt them.
- Make their decision based on data from outcomes of procedures.

Chapter 7

Conclusions

The main goal of this dissertation was starting to fill the gap in what the future surgical team will look like in the neurosurgery department, understanding how technology will evolve and what other aspects might influence its use. This way, the interviews with neurosurgeons allowed the following conclusions:

1. Healthcare industry and the neurosurgery activity in specific is a very subjective area, outcomes can be measured in very different ways and particularities like different techniques for the same procedure might not be counted in. Apart from that, this seems to be a matter that doctors do not pay much attention to or do not track directly.

2. There are many factors influencing the healthcare industry and the neurosurgical activity in specific. First, the anatomical constraints and adapted technology for the activity but also political, social, and financial aspects. This led to the confirmation of inequalities between different sectors but especially countries.

3. Job loss is not a main concern within neurosurgeons, since the working environment foreseen is one of cooperation between healthcare professionals, engineers, and technicians. Their main concerns are related to the impacts in patient care, due to possible lack of human connection, and legal problems regarding responsibility.

4. The healthcare industry must promote leadership and empower the workforce. These changes will lead to the increased need of different skills and training, but also the creation of new systems that support the surgical teams, improving their learning while not increasing pressure and workload. To train students and current neurosurgeons into

capable professionals there is a group of organs that must evolve together with the medical ones, like the education national system.

5. Due to the various challenges imposed to the evolution of technology in this area, creating more networking and brainstorming spaces between management, doctors and engineers could be a good starting point to understand how to create and manage this change in the management of the workforce, making sure the different sides complement and help each other.

Taking all these insights into account, some recommendations were made for different human resources work fronts. Nevertheless, the importance of developing other studies was referred, since this is a very recent and dynamic theme, that requires constant research and evaluation.

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Appendix I

Email sent to neurosurgeons to invite them for the interview

Good morning,

I hope this email finds you well.

My name is Ana Sofia Vinhas Monteiro and I'm a second year student of the Masters in Management at Universidade Católica Portuguesa. Before my masters I took a bachelor in Biomedical Engineering and in that sense I'm developing my thesis dissertation with the goal of understanding the current and future state of the neurosurgical activity and how technology evolutions will impact the future workforce in this area. Your name was recommended to me by Dr.X, and this way, I would like to invite you to an online interview, in order to understand your perspective on this matter and the reality of robotics in neurosurgery outside of the Portuguese context. If you are interested, the ideal time would be during the next week, since my dissertation depends exclusively on the outputs of these interviews. Nevertheless, as I understand your availability might be limited we can try to arrange another time, when possible.

Thank you in advance for your time.

Looking forward to hearing from you,
Ana Sofia Vinhas Monteiro

X - Name of the doctor who recommended.

Appendix II

Interview script

Topic	Subtopic	Theory	Source	Question
Robotics in Neurosurgery	Present of neurosurgery	"In the field of neurosurgery, different types of robots have different roles. stereotactic-navigation robots, primarily responsible for spatial localization, surgical planning, providing pathways for electrode implantation, and less involved in specific surgical procedures. In this mode, doctors play a subjective and active role, taking the lead in the surgery. "	"Neurosurgical Robots in China: state of the art and future prospect"	1. Taking the previous definition into consideration, what robots are implemented and used at your hospital?
		Gamma Knife surgery represents one of the most advanced means available to manage brain tumors; arteriovenous malformations and pain or movement disorders. Requiring no surgical incision to expose the target, the Gamma Knife can destroy deep-seated brain tumors and blood vessel malformations in the head once considered inoperable. It can also eliminate pain conditions and certain movement disorders, as well as silence malfunctioning areas of the brain precisely, to stop seizures—or ease disabling pain problems—that have not responded to other management strategies.	https://www.neurosurgery.pitt.edu/centers/image-guided-neurosurgery/gamma-knife	2. Present Gamma Knife. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use
	Future of neurosurgery	“First, as a precision medicine tool, it can assist neurosurgeons in developing personalized treatment plans. By analyzing an extensive cohort of patient data, medical records, imaging, and genomics, ML can identify patterns that predict treatment response for individual patients. Second, AI supports surgical planning and navigation. Patient imaging can be processed to enable more accurate surgical guidance and real-time feedback during procedures, thereby reducing operative errors. Third, AI enhances the efficiency and accuracy of large data processing, thereby improving diagnoses or uncovering novel therapies. Finally, AI has many important implications for medical education, providing new means of accessing data repositories, such as operative videos to personalize learning and enhanced patient education.”	"Artificial Intelligence in Neurosurgery: A State-of-the-Art Review from Past to Future"	3. AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?
		"With the development of Internet technology and the construction of 5G and other equipment and supporting facilities, the current network latency is decreased tremendously; Neurosurgeons can remotely use robots to perform surgery for patients who are physically far away with the help of the high data transmission bandwidth.[…] Remote surgeons only need to complete some important steps, and the surgical process can be further accelerated. In the future, remote surgery technology will continue to develop, and complete surgeries with higher operational accuracy and less delay."	“Neurosurgical Robots in China: state of the art and future prospect”	4. Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?

Influence of robotics in HR	Organizational structure	"This progress will require unprecedented levels of collaboration among engineers, surgeons, and healthcare operators to ensure that communication among all actors in the operating theater is improved by the new technology. Human–machine interaction will be a key factor for the success of autonomy in surgical robotics. Only platforms that can effectively communicate their intent and explain their decisions to their human companions will find their way into the operating room of the future."	"Autonomy in Surgical Robotics"	5. How is the department of neurosurgery formed at your hospital?
				6.How are the surgical teams formed at your hospital? [follow up with question about multidisciplinary if not mentioned, know if they work with engineers for example]
				7. Taking into account the future robotics in neurosurgery (AI, remote surgeries), how do you perceive the future surgical teams?
	Task distribution	Robotics can support human employees by offering them opportunities for more technical positions that are either created or enhanced by robotic technologies (Chao & Kozlowski, 1986). Robotic surgery is a notable example. Although robotics can enhance precision and reduce errors if applied correctly, the human knowledge remains a vital component (Jonsson et al., 2018).	"Artificial intelligence, robotics, advanced technologies and human resource management: a systematic review"	8. In a scenario where the technologies mentioned are fully implemented at your hospital, how do you see the change of task distribution? [between doctor and robot but also doctor and possible engineer]
		"Results show that intelligent automation technologies constitute a new approach to managing employees and enhancing firm performance, thus offering several opportunities for HRM but also consid- erable challenges at a technological and ethical level. "		9. What do you consider being the main challenges caused by the implementation of these technologies?
		"organization can improve process efficiency and effectiveness to improve productivity. Robots can perform a task every day, continuously, without human monitoring and can produce tasks error-free, which leads to a high quality and quantity of data. In addition, robots are more rapid, reliable, and accurate"	"Improving Efficiency and Effectiveness of Robotic Process Automation in Human Resource Management"	10. a) How are measured and tracked the following aspects? - success rate - productivity
				10. b) How do you think the implementation of these technologies will impact the following aspects: - success rate - productivity
		"organizations may have to work on performance assessment, promoting leadership, empowering the workforce [32] and creating incentives [33] in order to ensure the success of the organizational change. "	"Human-Machine Interaction and Human Resource Management Perspective for Collaborative Robotics Implementation and Adoption"	11. How do you think the implementation of these technologies will impact the surgical team's motivation?
	Capacity Building	"The sector should invest in training and development of their human resources, so as to keep their skills and knowledge up to date, which in turn would motivate the health care professionals to work in tandem with robots. "	"The Impact of Robotics on Employment and Motivation of Employees in the Service Sector, with Special Reference to Health Care"	12. a) What type of capacity building did you have to work with the present technologies?
				12. b) What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?
		"With the rapid development of virtual reality and other technologies, inexperienced doctors who have never used neurosurgical robots can quickly acquire knowledge and skills in robot-assisted neurosurgery through virtual training systems."	"Neurosurgical Robots in China: state of the art and future prospect"	13. How do you think education of future surgeons/interns should change taking into consideration the future of NS and new tools as augmented reality?
		"Given the continuous advancement of augmented reality techniques and their increasing popularity, it may be possible to develop a unified education plan for future neurosurgeons."	"Augmented Reality in Neurosurgery, State of Art and Future Projections. A Systematic Review"	14. How do you think education of medical students should change taking into consideration the future of NS and new tools as augmented reality

Figure II.1: Interview Script

Appendix III

Video shown in during the interviews about Gamma Knife

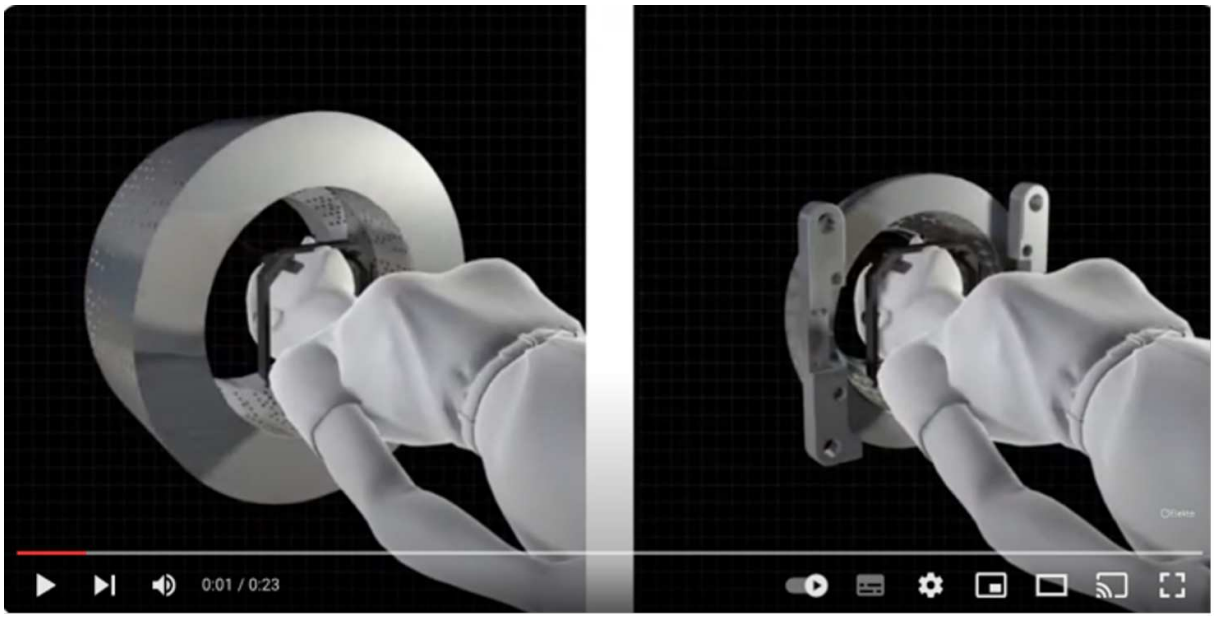

Figure III.1: Video shown in during the interviews about Gamma Knife. *(source: https://www.youtube.com/watch?v=bbZxohbp2eM)*

Appendix IV

Transcript of each interview

IV.1 Pilot interview 1 – Participant 1

H1: Hospital 1

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

   It is mainly navigation, we have robot arms that we use to help us with more precise either implantation of cables or screw positioning.

2. **[Present Gamma Knife] Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

   Yes. It is a very useful instrument within its proper indications and it has really helped treatment of lesions that surgically we could not access before. Even for lesions that we can access surgically, in some occasions, it has offered equivalent or better results in treating it, but under specific indications, it is not the treatment for everything but it has definitely improved our practice. The patient's safety and the effectiveness towards them.

3. **Do you consider that there are disadvantages?**

   Everything has its disadvantages. Besides the obvious, like the fact that there is radiation and passes through tissues to get to the target. Obviously, the main disadvantage is the fact that because of being noninvasive, and because it can sound more appealing to the doctors and patients that may want to avoid the operation and may want to avoid the risks, it can

be overused. Unless there is proper consultation of the patient or proper multidisciplinary discussion of the case, we may expand the applications even in cases where we should be operating. It is necessary to have appropriate and honest discussions with the patient about radio surgery.

4. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

   The way it is presented, that is the goal, and the hope is that it will actually help, since the goal is to help the patients the best way we can. The maximum effectiveness with the minimum damage or at least potential risk. The thing is it has not been tried yet, the AI systems are now being developed but the hope is that in the near future we will be able to use it and improve the level of care we provide our patients.

5. **So are you a believer that it might work and be an asset for the area?**

   Everything has its use, advantages and disadvantages, like every instrument, if we use every instrument in the appropriate way and indications, everything can be advantageous. When we step out of these indications then we run the risk of dealing with its complications or ineffectiveness.

6. **Do you believe that it should be created some kind of regulation so these problems can be controlled?**

   Of course, the question is who will be that regulator, who has enough knowledge or experience to do that? The process that has been set up mostly in the western medicine at the moment, not what happened 50 years ago, right now we access an instrument, give the recommendation and then through trials we see how safe this recommendation is and then we take the application and then during the application we reevaluate our choices and limits. Gradually with every step we get the knowledge and experience with instruments and medication.

7. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   There are places in the world that do not have access to high quality or high literate neurosurgeons, so for these occasions it would be extremely useful and in many cases

lifesaving. But once again it is the same conversation where we need to assess how we implemented that, where to push limits and set barriers. Hopefully yes, we will be able to be doing as much as possible from a long distance, but it will be very difficult to replace the in person care and personalized care that the patient gets from face to face conversations with the healthcare provider. Even for the decision making, I mean, for example, the tactile feeling that surgeons get when they operate, technology really must advance a lot to give that feeling from a long distance. Until that is replaced, not only for neurosurgery, it will be a counterargument to these technologies.

8. **How is the department of neurosurgery formed at your hospital? How are the surgical teams formed? (may vary on the procedure but in a general way for me to adapt to the reality)**

   So, in our department and almost every department in the UK, there is not a clear head of the department as in one person that makes all the decisions, there are multiple individuals, specialists, junior doctors and trainees. The surgeons themselves are organized in small groups of 3 to 5 specialist that subspecialize in a certain aspect of neurosurgery. There is a certain group for spinal and so on. All of that of course when we are talking about the on-call service. For emergences everyone has to give some input on a broader scale, but it is very rare that someone has to do an operation outside of their subspeciality.

9. **Taking into account the future robotics in neurosurgery, how do you perceive the future surgical teams?**

   I think that the model in Manchester is a quite possible a scenario for the future. Fortunately, or unfortunately that sometimes is not only affected by the effectiveness of care or the level of care, for example there are many countries that do not want subspecializes doctors, they want general doctors that can do everything, in the hope to employ less doctors, what will cost them less. Having subspecialized doctors doing 1 or 2 specific things does cost more, because you have more doctors and specialized equipment. That is more of a political decision and a decision that will depend of the overall financial and social conditions rather than how the technology will evolve.

10. **How do you see your job evolving in the future? Do you consider that in the future robots can substitute surgeons?**

11. **How do you think the evolution of robotics in NS will impact your tasks?**

    I think that the main thing that will change for us if it applies in an affective way is if for example AI improving the diagnosis and the quality and speed of imaging. That could potentially lower the waiting time for patients to be referred to a specialist service as in the initial diagnosis. Because obviously if the patient is followed by a certain team they tend to follow up the patient closely and react quickly. As neurosurgeons we can read our own scans we don't really rely on the diagnosis from radiologists, we ask for their opinions when we struggle, but other specialties are not trained to read the scans on their own so sometimes they rely on the diagnosis to report to us.

    This is something that may change if AI in applied. Other aspect that I think will improve when the robot arms become faster and easier to use, because now using one for a biopsy is a big effort. When they become like the navigation systems, implanting electrodes or screw positioning, spinal surgery will become significantly faster and more accurate. It will have even less problems with planning these operations with AI and executing them with robotic arms.

12. **Do you work with people like engineers or technician to help doctors with this type of technologies of do you feel is not needed?**

    What usually happens is there are at least one or two people that get special training to use these machines, they get some troubleshooting training and so after that, they are the ones that lead those cases. Obviously, if a patient requires a biopsy with a robotic arm, this operation is done by those surgeons. If a third surgeon does the operations, they are there to help. But when we have problems there is always an available technician to assist the situation.

13. **Are they available at the moment or takes a while?**

    Usually, we call them during the operation if we are struggling, for them to be available to come in person, might be a challenge, for example if we know that in the following day, we have an operation with a device and in the last one we had problems then the technician will make arrangements to be there to assist.

14. **Do you believe that the system (calling by phone) might change with future technology, or you think will work for the future?**

It depends, most likely it will not change because even if we do a videocall and show them the problem, if there is something technical that we are not trained to do, they will need to come. I don't know if they can start repairing things remotely, but in the meantime, they will need to come in.

15. **What do you consider being the main challenges caused by the implementation of these technologies?**

    The main thing is cost as always, because those machines cost a lot and unless they are clearly advantageous, what would reduce the cost overall, for them to be bought by the hospitals the cost will need to be justified.

    The fact that they are fancier or more modern is not and argument, the hospitals are run by managers either private or public, so if the managers are convicted that it will be cost effective then yes, it doesn't really matter how good of bad the technology is, if costs doesn't overcome the benefits.

16. **In terms of using them you don't see any challenges that this technology might affect your activity?**

    We all have seen movies like the terminator, machines do everything, and we end up without a job, having seen all of these we have that in mind but in reality, we can't deny progress just because it doesn't suit our lives choices. If that's the way that it is better for the patients, as in effectiveness and safety, and it improves the quality of care that should be the most important thing and everything else should be accommodated to that rather than the other way around.

17. **How are measured and tracked the following aspects?**

    - **success rate**
    - **productivity**
    - **motivation of surgeons and surgical teams**

    I don't think that there is any metrics for that (motivation) or that I'm aware of, obviously someone that is very prolific in literature and can show that they do more operations than the others and they can publish their results and those are validate, when they suggest new ways of doing things, they fall into the category of expert. The way units like mine are organized, with subspecialized people, they can be considered experts in that subspeciality.

18. **Do you think the motivation of surgical teams can be affected by new technologies and is so in what way?**

    That's a difficult question, surgeons tend to be motivated individuals by default. If they are not motivated individuals, they are not good surgeons and if they are not good surgeons no technology will save them. I don't think motivation will not be really affected by any technology.

19. **In your case that are certain people who are receiving training to work with technologies. What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?**

    It is very important to train not only the surgeons but all of the staff. I'm a strong believer in knowing very well a certain thing instead of a little bit of everything. The nursing staff should be subspecialized, anesthesiologists should be subspecialized as well, and all of them should be doing specific operations. The nurses must know how the robot works, so that they can all be faster, more effective and take better care of the instruments, overall that makes things easier for everyone.

20. **How do you think education of future surgeons should change taking into consideration the future of NS and new tools as augmented reality?**

    The hope is that the technology will evolve to actually improve the training. Previous generations led on patients, and when that happens within a safe environment that's fine but 50 years ago the environment was not that safe. We did have problem that might have been overlooked. In the 70s they trained on patients whereas other generations train on cadavers and models and because cadavers cost a lot and having a lab is not an easy thing, models made of plastic is a big step forward for trainees, to learn how to use the instruments, basic anatomy before they go in and try on the patients. It will be extremely useful, having done this with trainees, they were doing it more confidently after, more effective and most important it was safer for the patient.

IV.2 Pilot interview 2 – Participant 2

H2: Hospital 2

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

   At my hospital, at the moment, we don't own a robot for neurosurgery. I think robots in neurosurgery are relatively recent, for my specialty, spine surgery, I think that there are 3 robots in the world (mazor, rosa and excelcius), mainly for screw positioning and improve the precision. From my point of view owning one demands a big investment, I think that they were already tested in Portugal but I think not bought. In our hospital exists the DaVinci robot for general and urologist surgery.

2. **[Present Gamma Knife]. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

   Yes, I am.

   I believe that this technology has its advantages. It enables less invasive treatments, these procedures are already performed in spice surgery, when lesions are in difficult access areas. It has many advantages in patients with multiple metastasis. Nevertheless, it has some less positive aspects, while a surgery removes the lesion, Gamma knife only deactivates it. Besides that, it can occur an inflammatory reaction, an increase of symptoms in the first months and then reduction. I think it should be perfected so it can be even more advantageous.

3. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

   I've read and thought about this. AI is a method of inevitability, it will and should grow and it will help us a lot. In medicine it is based on the premise that sometimes might not be correct, it assumes that we know exactly the right way to treat a diagnosis and a lot of the times we do not have scientific evidence that treatment A is better than treatment B. With a patient with a lumbar disc herniation, we know that we can do 5 techniques, all of them have advantages and disadvantages, but it is not possible to try every single one of them in a single patient to understand which one goes better. This way it is difficult for AI to guarantee which one will work better. But I also believe that AI can be useful in

solving this, by establishing better comparative studies and using self-learning features. Without any doubt it will be a great help.

4. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   I see it in a distance way. What I mean is technology will advance but I notice that sometimes things fail, even if they are by far better now than before. But someone who is educated today, only with the present technology, if they don't have the "know how" of doing it without technology can take the change of not knowing what to do if technology fails. Besides that, if it fails and I have the patient in front of me, that's fine, but what happens if it is a remote surgery? In some situations, it might be possible but it is important to have a surgeon nearby.

   Even from a legal point of view, I don't know to whom I should pose the problem.

5. **How is the department of neurosurgery formed at your hospital? How are the surgical teams formed? (may vary on the procedure but in a general way for me to adapt to the reality)**

   Our department is a bit hybrid in a way that in a private hospital there are a lot of doctors from public hospital that work for both. We have some who work for both and some who work only for the private sector. We have a group of doctors with similar characteristics and some that are specialized in a certain are of technique.

6. **Do you work with a head of the department?**

   Yes.

7. **How are the surgical teams formed?**

   Each doctor has the consultation period, from the patients observed some will have to go under surgery and will be operated by that doctor. That surgeon has another surgeon assisting, usually always the same, such as the nurses and anesthesiologist, which are "subspecialized" in neurosurgery.

8. **Taking into account the future robotics in neurosurgery, how do you perceive the future surgical teams?**

I believe that AI will help us mainly in the consultation, in the clinic decision making. At the intraoperative level I think it is still a bit futuristic, it might be possible, but I think it will always important to maintain a team such like the one we currently have.

For remote surgeon I think it is fundamental to at least have a pair of human hands near to the patient. Maybe we can have a situation in which we only need a surgeon, a robot and someone handing and separating the instruments. It is possible that one day we only need a surgeon operating remotely, one near the patient and one anesthesiologist.

9. **And do you consider that taking into account these technologies, it might be necessary to include other jobs in the field, like engineers or technicians? And if so, how?**

   I believe that they are crucial, and we already work with engineers from the industry. For example, with the navigation system for spine, we have 2 engineers with us. It is very important to have biomedical engineers with us because they improve the way of thinking and the problem solving. I feel more comfortable when they are there during the surgery.

10. **How do you think the evolution of robotics in NS will impact your tasks?**

    Above all I think the role of a neurosurgeon should be taking the decision, it could be suggested by the robot but should always be validated by the surgeon, a step by step validation, where they work in a symbiosis.

11. **What do you consider being the main challenges caused by the implementation of these technologies?**

    The easiest thing is looking into the past to see the future. I've always seen resistance from surgeons and healthcare professionals when it comes to implementing new technology, mainly because in the implementation phase something that would take 2h might take 4h, what can be seen as a reduce of productivity and effectiveness.

    Also we have to take into account the learning curve, with technology what it seems is that there is a need for time, to perfect certain aspects and learn by doing.

    Besides that the idea of rise of the robots is always present in the back of the patient and the doctor's mind. What is there is a bug? If the robot does the opposite of what was told to do? That might be an emotional aspect for both, when someone is sick. The system might stop, and this type of situations might difficult the implementation, but the "path is made if walking" and I'm aware that there will be challenges that we have to overcome.

Besides that, in a private hospital if someone has to go through surgery usually, they have an insurance. Every time we add and new technology the price increases and that is another thing to cause resistance. We notice that until insurance companies started to contribute towards spine navigation it took a lot of time and patients don't want to pay more.

12. **How are measured and tracked the following aspects?**

    - **success rate**
    - **productivity**
    - **motivation of surgeons and surgical teams**

    Yes, there is. The data is collected in a very raw way and needs to be improved. There isn't a special attention to make the data accurate. There is not differentiation on a type of surgery that has 5/6 different ways to be perform, but we are working to improve it. From a productivity point of view, the times are very well studied, it is even the systems that tells us the time a certain surgery will take, taking into consideration the procedure.

13. **How do you see these technologies impacting those aspects?**

    We don't have data about that yet. I notice that doing surgeries becomes faster, safer, for example after the navigation system it has never been necessary to review wrongly positioned screws and decreasing that to 0% is the best we can have. That also reduces costs since it is one less surgery we have to perform.

14. **Do you think it might affect people's motivation?**

    The truth is that healthcare professionals are already under a lot of pressure and bureaucratic burden. People are tired and it can cause resistance and difficulties motivating people. There are people who easily adapt but not everyone is like that.

15. **In your case that are certain people who are receiving training to work with technologies. What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?**

    It is really important to create training initiatives about new technologies. There are already some for neurosurgeons, but they are elective, so people have to invest their own money and time. I think the best option would be having a month or 2 weeks where

neurosurgeons would go and collaborate with biomedical engineers to learn with them, creating a sharing environment. Otherwise in the future we might be run after the damage, struggling to learn.

16. **How do you think education of future surgeons should change taking into consideration the future of NS and new tools as augmented reality?**

    There should be elective courses for students who are interested in that.

IV.3 Pilot interview 3 – Participant 3

H3: Hospital 3

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

   Yes, we have robots at my hospital. Honestly, I don't remember the name, I think there's only one in commercialized right now.

2. **What does it do?**

   We are using mostly for epilepsy surgery, particularly then we are implementing some for stereotactic biopsies.

3. **[Present Gamma Knife]. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

   Yes. In in my experience the main advantage of the surgery is related to the lack of anesthesia, no need of general anesthesia. We can perform a specific treatment with a very low risk. Advantages are related with the effectiveness of the device, less risk for the patient, in tumors in challenging places, tumors located in deep structures, which would be difficult to access with.

   Disadvantages are related to the lack of effectiveness and particularly with the time needed for the treatment to present its effect. For some tumors we may have to wait some years to see for example reduce in tumors.

4. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

   AI is a big promise for the future, personally I'm excited thinking about its use in the field. Strongly agree with the statement, it may help in taking difficult decisions and developing guidelines. I do not want to hide the dark side of AI, mainly related to the lack of control of the surgeon of the process behind the AI. We are receiving good suggestions from AI but don't know from where they are coming from.

   A closer friend who is a lawyer and I are working in medical legal issue related to AI, in case the machine is suggesting a certain procedure, and this is revealing to be wrong, who is going to blamed for the responsibility of what happened? The producer? The industry? The hospital? I think that there is something about European Union regulation, from May 2023, that gives some suggestions about this, but the incoming adoption of AI will be promising but also complicated.

5. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   Surely, I really agree that AI can be a big help for the surgeon during a surgical operation, it can provide assistance but I don't think AI would be able to perform autonomously some procedure but it would be a big help. What I'm thinking now particularly is for example when operating we usually use systems to magnify the surgical field, in the past this would not happen, now there are digital reconstruction of images and so it is possible to add and subtract some information. AI would be able to tell me guidelines about what direction to go in for example, at the very end the decision would come from the surgeon so it would be a suggestion. It is our job to take the decision.

6. **Which problems do you see in this possibility of remote surgery where you are in other location?**

   First of all, technical issues, I do not to image what may happen if the connections fails so we need someone in the hospital in order to take control of the situation. Secondly, specially neurosurgery, the surgical procedure is just a part of a bigger plan so patients might need to stay for a few days in order to manage possible complications, if it is remote

it could be not easy to manage possible complications. Maybe the personnel could be not trained enough, and it could be a risk for the patient.

7. **How is the department of neurosurgery formed at your hospital?**

   We have a head of the department, then we are 16 neurosurgeons plus the head, we are working in small groups of 2/3 people, each group is focused on a sub flied of neurosurgery, it is mainly working in that subfields, in that way we have a pretty dynamic organization.

8. **How are the surgical teams formed at your hospital?**

   In a general way all our procedures are performed at least by 2 surgeons, 1 younger one and 1 senior, the younger one is a resident in order to complete their training, for some specific challenging surgeries there can be more than 2 but it is not so common.

9. **And this group of surgeons working in the same surgery are they always the same?**

   They stay the same.

10. **What about the nurses?**

    Yes, the same.

11. **Also since you have a robot in your hospital do you work with engineers and are they present in the operation?**

    We are working with technicians they are always present in the operation in order to control the device, we had engineers in the first phase (1month or less), they trained the technician about the device and now they are not present anymore in person, only the technician. In case of specific procedures that we are not trained for or malfunctions we call them, and they come in.

12. **Taking into account the future robotics in neurosurgery (AI, remote surgeries), how do you perceive the future surgical teams?**

    I don't think the technologic development would change the surgical team, technology will be present together with the human being, but not replace them.

    Administration would plan to increase the technical personnel able to use machines and possible to fix possible problems of the device. It is something that in the future should be considered.

13. **In a scenario where the technologies mentioned are fully implemented at your hospital, how do you see the change of task distribution? [between doctor and robot but also doctor and possible engineer]**

    It is a difficult question, the two teams (of doctors and of engineers) would be present at the same place, work together but I do not see any exchange of competencies, just probably a contamination. The doctor does not have engineer competencies and engineers are not doctors.

    Both of them are too advanced responsibilities in order to have someone able to do both.

14. **And what about doctor and robots, do you see your tasks changing?**

    Yes, in that sense I see a possible sense, some neurosurgical procedures require precision and robots are more precise than humans. Another problem is the time-consuming procedures, humans get tired but robots don't. The 2 concepts would run together in a sense that the longer the surgery the less precise it can turn out, the possibility to make mistakes might increase. For those surgeries, that have repetitive tasks, surely robot would be better than us and would avoid those problems, giving advantages for the patient.

15. **What do you consider being the main challenges caused by the implementation of these technologies?**

    Technical challenges for sure, right now robots are still not perfect for the neurosurgical needs, neurosurgery is a small field, I can imagine robots evolving a lot in other departments, so there is a lot of work to do to make them suitable for neurosurgical fields.

    Also the protocols we will use in order to use those devices, there are a lot of scenarios but it can happen that these protocols will be developed by each hospital (in order to use AI, robots, remote surgery) or it can happen that we are going to a big validated and shared protocols common for the large majority of centers. Both scenarios have advantages and limitations, if you have your own then you have something very close to your needs but may have more mistakes, if it is something shared it should be something very solid but not that adapted to each needs.

16. **(a) How are measured and tracked the following aspects?**

    - **success rate**

- **productivity**

Success rate is not easy to be measured in neurosurgery, because the aims of a procedure in the brain are multiple so it should be another way to analyze the success rate in neurosurgery.

For productivity, we are doctors so we should perform surgeries, that's the way to be productive.

(b) How do you think the implementation of these technologies will impact those same aspects?

In the future the most important success rate will be the quality of life of the patient, the possibility of the patient to keep the quality of day-to-day life.

For productivity maybe we can reduce complications, reduce the time of surgery (many ways to do that, like training and the concentration of pathologies in some specific centers and on specific people inside those centers, high volume center would be able to perform the same surgeries with less time and less complications).

17. **How do you think the implementation of these technologies will impact the surgical team's motivation?**

    A surgeon is motivated by his or her good results, if those devices are increasing results and enabling us to perform better, than the team will be more motivated.

18. **(a) What type of capacity building did you have to work with the present technologies?**

    Training consists in the presentation of technology by the engineers, showing how it works and helping us in the first procedures.

    (b) What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?

    In the future maybe simulations not in real patients will speed up the learning and training with future technologies.

19. **How do you think education of future surgeons/interns should change taking into consideration the future of NS and new tools as augmented reality?**

    The education is really changing, I received mine more than 10 years ago and most technology I'm using now was not present at that moment, the residents now are receiving

a completely different education. Learning how to use it as soon as possible so they are successful in the future. They are starting from the very beginning to use technology devices; it is very clear in their mind that if they are not able to use those devices they won't be able to perform some procedures.

20. **How do you think education of medical students should change taking into consideration the future of NS and new tools as augmented reality?**

    Most medical students are very scared by surgery and neurosurgery so it is not a popular field among them, it is very important to select the ones with some inclination and specific skills with technology because they will have a better learning curve.

IV.4 Pilot interview 4 – Participant 4

H4: Hospital 4

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

    We have programs that help us planning the surgery, neuro-navigation systems which is a passive interaction. We tried robots with arms but are not implemented yet. Nowadays we are implementing AI in the workflow, still in research process, for planning surgery.

2. **[Present Gamma Knife]. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

    Yes, but we don't do it in our hospital, it can have some advantages with patients who cannot go under the surgery. It has to be balanced, there's always more than 1 possibility in medicine and it is good to have options but we have to be cautious to offer the best thing to the patient. I know how it works but we don't perform it here, it is in the radio therapy department that we work closely with.

3. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

In my opinion there are different fields where you can implement it. In my experience it is more in the radiologist department, in reading MRIs, that's for sure one of the possibilities, see the data pretty easily. For the surgery it is more difficult because there's always the problem who is responsible. In the intraoperative environment I think it would be interesting in matching the brain shift (taking the tumor the brain shifts, so learning how it changes and implement it in the neuro-navigation systems), to control stereotactic navigation, may have the control of AI since it is a straightforward procedure, checking if it is right or wrong. Also, the in pre operation, which kind of clip, stool to use, there's something where AI could help, and then when you are in the surgery has a control system. You have to be aware that you can be improved with AI, the dream is that you bring the patient into a capsule, and it is operated but probably won't happen due to the hardware, the robots are still something that helps the surgeon not replace.

4. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   There is a very established system called the DaVinci robot used in urology and general surgery. Remote surgery is something that you can perform but in the brain is very difficult because you have very small access, they tried to use DaVinci but it was not super successful. Completely remote is possible but the problem that I've seen is in the end if something goes wrong you need someone there who can save it. I see there is a potential in some situations, for example Greenland is depending on Denmark, but it is not something to offer on a daily basis, maybe useful for development countries. For spine is probably easier if you have a robot that can perform that, that would be closer in the future but intracranial surgery is too difficult.

5. **How is the department of neurosurgery formed at your hospital?**

   We have a director and a vice chief, it is not a special unit but we have 3 of people with more experience, around 10 attendings, one department for pediatric neurosurgery which is kind of alone, in total 30 people including the chief. We also have students as practical years integrated in the clinical workflow but taking care of basic tasks. We don't have a formal division into subfields.

6. **How are the surgical teams formed at your hospital?**

They are former by 2 surgeons, usually 1 attending and 1 resident, may happen 2 attendings if there is a challenging procedure but it is not usual.

7. **What about nurses?**

   Nurses they are one at the table and one stays outside to bring stuff (sometimes they share the one outside between procedures), they rotate so it is not like a fixed team. We have some sub specialization between the nurses, for example we have 2 CT scans intraoperative, so we need nurses who know how to use these things but it is not something that is fixed.

8. **Do you have engineers or technicians?**

   No engineers, no technicians, we work on our own, unfortunately.

9. **Taking into account the future robotics in neurosurgery (AI, remote surgeries), how do you perceive the future surgical teams?**

   I would say that in the end, you would be able to reduce the team in the dimension but not reduce the people who are involved overall, maybe just one surgeon if there's some kind of robotic arm that is holding the suction. Probably a shift of the people who are involve, but we will always need at least a doctor, nurse and probably a technician. The technology that we have are run and used by us, besides when there is any specific problem, which is in the end in my opinion a limit, because you never use it to the maximum and we don't get the feedback to improve and progress faster.

10. **In a scenario where the technologies mentioned are fully implemented at your hospital, how do you see the change of task distribution? [between doctor and robot but also doctor and possible engineer]**

    I think robots could help on a daily basis during everyday life tasks in the department, like distribution medication, something that is easy to do and to implement, giving food to the patient. For all the patients who need a care giver it will be a slower process, I see a more hybrid personnel working around the station, since of course nurses will be there.

    Where I see huge help of AI is in the management in the huge number of bureaucracies, for example taking the data and give us a letter of discharge.

    Also, in operational planning and optimization, using the capability of the hospital as its maximum, scheduling operations, and stuff.

I see a shift in low profile job, which I fully respect but will probably slowly go out because they will reduce time consuming tasks for the nurses and reduce errors due to tiredness, all of this would let us focus on more important aspects of the job. We will need technicians, way more than now, and I believe that will be a problem since it is difficult to get people to work in the healthcare system.

11. **What do you consider being the main challenges caused by the implementation of these technologies?**

    Responsibility is a huge issue, there's a person that will have to take the responsibility, either company or insurance will have to take it and also maybe implement other features rechecking if the process is going though correctly.

    Also, the human connection, in my opinion it is really important to never forget that we are in hospitals there are a lot of psychologist component with patients. Human connections is important to keep into consideration, of course we need to be sustainable but we don't need profit and that it is key to decide. Technology brings the precision to treating better the patient but don't forget they are human, and they are sick. Technology is welcomed and probably will improve treatment and reduce the failure, but we cannot substitute the human connection.

    On the other hand what I see in Germany is not the humanization but the burn out of people in the healthcare system which are more and more under pressure and the implementation can help people to focus in what is important, but has to be used in that way and not only to achieve higher numbers.

12. **(a) How are measured and tracked the following aspects?**

    - **success rate**
    - **productivity**

    They are not tracked, the success rate we don't measure, we may have data base for research purposes but not systematic. We have an economy department, they see how many operations, how many patients and how much money.

    (b) How do you think the implementation of these technologies will impact those same aspects?

In my opinion no, I'm 100% sure that if you check the success rate of very good surgeons it is probably lower because it depends on the challenge you face. Data, as we learned with covid, is important but you really have to be aware on how to interpret rate. I don't want to have medicine that is based on numbers and which kind of success rate you have.

13. **How do you think the implementation of these technologies will impact the surgical team's motivation?**

    No. I don't think it will impact, I don't think it will impact negatively for sure maybe more positively since it is exciting to have new challenges.

14. **(a) What type of capacity building did you have to work with the present technologies?**

    In the medical field there's a lot of self-learning, we have a structure we follow but no special training or any kind of degree. Most training is from workshops from companies, to be aware of what we have.

    (b) What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?

    For sure workshops and initiatives for nurses and doctors, the lack of people involved in the process is a problem so more workshops.

15. **How do you think education of future surgeons/interns should change taking into consideration the future of NS and new tools as augmented reality?**

    The best is still the cadaver approach in my opinion but it is hard to get them. In the future I believe some recreations will take place, creation of structures and materials similar to brains for training purposes. Then you can do 100 per day and really train and evolve. It will also reduce the use of animals, for example no one can learn bypasses on humans it is impossible. Those things including AR will improve education and open other possibilities like fake hospitals, like scenarios where you go inside, and you are completely emerged and solve a case. It will revolutionize the way of learning and tools are there to be used.

16. **How do you think education of medical students should change taking into consideration the future of NS and new tools as augmented reality?**

    I find kind of sad that most of the exams are a list of information that you have to bring there, it is important to know basic knowledge but the information is always available,

everyone has to do research sometime so in my opinion it is important to be able to interpretate. That will be the doctor of the future.

IV.5 Pilot interview 5 – Participant 5

H5: Hospital 5

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

   Yes, I've been working with robots especially with neuro navigation systems. It helped me during and before surgery. Also practicing with some robots to help with skills and I believe that virtually reality is also a topic that can be added to the daily routine and help us a lot, improving the activity.

2. **[Present Gamma Knife]. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

   Yes , but I never worked with it. I think radio surgery is the typical example where the machines help us a lot to perform better because you can plan and also there is the robotic arms that moves around the patient and the precision is for sure better than humans'.

   It is a good example where robots can help us, also companies push a lot for the existence of robotic surgery for the spice, if you have a CT and want to position a screw, since a machine will be more precise than a human being, I believe that in this type of surgery will continue to help even more in the next years.

3. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

   I believe that some specialties would not be replaced but highly improved and automatized with AI, pathology for example, some tumors can be diagnosed with a data base and explored with AI.

   Traditional radiology may be replaced in the sense that a machine may be more precise, and so I believe that some specialties are at risk but surgery is one of the last specialties

that will be replaced because there are a lot of things you have to analyze and possible complications to manage, it takes time to make the robotic arms do what AI tells it to do. It may take more than 50 years but we cannot know if it will or when it will happen. Some scientific societies have to discuss a little be more about the philosophic matter to decide what will happen.

4. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   Of course we have all seen the videos of the surgeon who sutured the banana from England to California. It is a good solution for developing countries where there is not a lot of surgeons but there are disadvantages. Technical problem is the first one, the second thing is (that is one of my main issues) that you will lose the human connection with the patient, and of course in an emergency you will save the life, but for other cases, not so urgent ones, I think medicine is not just performing the surgery. I like to establish the relationship, the technical thing can be replace, in the future, the human factor remains part of the health process. I'm totally pro this type of technology, but should not become the rule.

5. **How is the department of neurosurgery formed at your hospital?**

   My department now is not so big, I'm the head of neurosurgery there. There are 3 other colleagues. Subs specialization is important but we are not strictly sub specialized because we are quite small. Before I worked in a bigger department, I was in charged for skull based, with the help of my former boss. I believe that sub specialization is the right way to work, if the number of doctors permits it.

6. **How are the surgical teams formed at your hospital?**

   We have different scrub nurses, they are not many at total, so we work with everyone but 2 of them are more specialized with neurosurgery.

   The same for anesthesiologist, it can help in emergencies that you work with one that is not specialized. The doctors work with everyone, I think it is important for training to work with other colleagues. I sometimes learn from residents, so rotation is important. When I have a difficult case or navigation not standard cases I always ask for the engineers to come there. I prefer to have someone who is specialized in this field and can help me if there is any problem.

7. **Taking into account the future robotics in neurosurgery (AI, remote surgeries), how do you perceive the future surgical teams?**

   Yes, for sure, the surgical team is evolving, it is no more a one man show. We were trained that the boss was the only good surgeon, but it is no more like that, nowadays there are subs specialization. Engineers, company staff who are specialized with a particular robot or machine are appearing more in the field. Real multidisciplinary teams with medical and non-medical staff are the future.

8. **In a scenario where the technologies mentioned are fully implemented at your hospital, how do you see the change of task distribution? [between doctor and robot but also doctor and possible engineer]**

   I think that there are different scenarios that are possible, some non-medical teams like engineers will be more a necessity in the future hospitals. It depends a lot on the government of the country if they let them do something. Sometimes there are laws to let you perform determined procedure and I might need an engineer to go there to tell me what to do.

9. **What do you consider being the main challenges caused by the implementation of these technologies?**

   Ethical problems because at the end if a machine performs everything how can we be sure it respects ethical problems. The decision making is an important part of the process and it is difficult to program the machine to know for sure the right way to do it and take the right decision.

10. **(a) How are measured and tracked the following aspects?**

    - **success rate**
    - **productivity**

    Being at private hospital is something we take a lot into account; the main thing is the budget, we have to perform a certain number of surgeries to reach the planned goal. If the outcome is not good, this is considered and the direction will talk to you if you are doing well or not. The fact the money has a big focus can also be a good thing, metrics are tracked, like the average of recover bedtime of your patients, if it increased from one

month to another, it might mean that you only operated on very difficult cases, but it is quite difficult that you change your case mix in only a month. We will have to explain that, so this side of the private sector forces you to perform better.

(b) How do you think the implementation of these technologies will impact those same aspects?

It will change in the future with the implementation of technology, but also because we will have more and more data to analyze what at the end of the day pushes us to do our best.

11. **How do you think the implementation of these technologies will impact the surgical team's motivation?**

    Yes, but in a positive way, not in a negative way. I think the technology is making me young by mentally, be available to adapt and more technology will make me more motivated since it allows me to perform better and achieve better things for patients.

12. **(a) What type of capacity building did you have to work with the present technologies?**

    The problem is that I learned on the patient, it is not right but it is the real thing, until some years ago, surgery worked like that, you would perform your first alone surgery on a real patient. Nowadays there are simulations but to become a surgeon you can do 0 hours of simulation and start on a patient. We have the technology now to change that. Ten of fifteen years ago when I was in training it was normal to start from a patient.

    (b) What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?

    I think that big companies work a lot to give all their stuff (Google, Amazon, but also medical companies), the working place should change a little bit, if I have small children I should have the possibility to have a kinder garden. Also more team buildings, working together everyday doesn't make you a team, it is something more. Not only professional skills but also relationships, and third we should have the time to study and investigate about the new technology, a new technology comes out I have to learn how to use it in a simulation setting. At least in Italy, the third one it has become more usual, at least there is an expert who comes to hospital and showcases but the two first topics are lacking a lot, the environment is something very very bad. Public or private, private may be ahead but

we have to improve a lot.

13. **How do you think education of future surgeons/interns should change taking into consideration the future of NS and new tools as augmented reality?**

    I think that this is a main theme. It will be very useful; you can share your knowledge and simulate the operation and learn faster and maybe better. Accelerating the learning curve and making a lot of things easier to understand.

14. **How do you think education of medical students should change taking into consideration the future of NS and new tools as augmented reality?**

    This is a big and important question because I think that in Italy is like university prepared you in a theoretical way and something that we miss is how to use technology. I think we have to implement courses that are dedicated to work with big data, AI and also some technical knowledge on how to use a robot, how to perform better with them. Education will change for sure, but I hope that it will be more practical and also there will be some education in technological part.

IV.6 Pilot interview 6 – Participant 6

H6: Hospital 6

1. **Taking the previous definition into consideration, what robots are implemented and used at your hospital?**

    At the moment I'm not using na autonomous robot, I've used robotics arm but we perform all the activity. Also we use the neuro navigation system, like. GPS that helps us find certain points in the brain and spince and the brain stereotaxy based on cartesian coordinates.

2. **[Present Gamma Knife]. Are you familiar with it? What do you think about this technology? You can mention for example advantages and disadvantages you see with its use.**

    Yes, but I never used it. It can be considered to revolutionize neurosurgery, it has the advantage of not opening the skull and hurting important brain areas. But it also has

disadvantages, some doctors believe it can create dysplasia, and also it should not be used near nervous structures.

3. **AI is a growing trend at the moment, it is said that it can help surgeons in diagnosing, developing personalized treatment plans and even surgical guidance during procedures. How do you perceive its implementation?**

   In the healthcare industry AI can create algorithms to guide the patient to a certain area, helping with the diagnosis, from the intraoperation point of view I consider that its use still had a long path to go, since anatomy can vary a lot from one surgery to another, from patient to patient, what damages one might not damage the other, so it is hard to create a algorithm. For the planning I believe it would be a big advantage, even more for spine surgery.

4. **Another main prospect for the future of robotics in neurosurgery is the possibility of remote operations. How do you perceive this possibility?**

   It was performed in Coimbra, a French or Spanish neurosurgeon helped in a surgery. It is a way to learn new techniques without going abroad and affecting our personal life so much.

5. **How is the department of neurosurgery formed at your hospital?**

   I've worked in hospitals where we were divided in areas, like neuro oncology, spine surgery, functional neuro surgery, vascular neurosurgery, skull base and trauma neuro surgery, each are had its coordinator and a general director. At my current hospital, we are fewer so there isn't any type of sub specialization.

6. **How are the surgical teams formed at your hospital?**

   We work with 1 senior neurosurgeon and another doctor assisting who usually is an intern, this intern rotates as well as nurses and anesthesiologist. There's a group of anesthesiologists who are specialized in neurosurgery, they rotate among them. I consider that it is important the specialization of nurses, but it is not always possible. At the moment there is only the sub specialization for the OR, not for neurosurgery.

   I have also worked with engineers who plan the surgery and are present in the intra operational environment to monitor the navigation machines. I've worked with neuro physiologist, who monitor a nervous lesion and help us during the surgery.

7. **Taking into account the future robotics in neurosurgery (AI, remote surgeries), how do you perceive the future surgical teams?**

   I believe there will always be the need to have a surgical team like the ones today, because if we have a bleeding, we have to prepare ourselves for an emergency, with e regular team. There is no robot prepared with a specific algorithm for emergence, but I believe there will be the need to incorporate more engineers with the evolution of technology.

8. **In a scenario where the technologies mentioned are fully implemented at your hospital, how do you see the change of task distribution? [between doctor and robot but also doctor and possible engineer]**

   I can't answer that question, the surgeon will always be necessary, any bleeding can become and emergency. So, I believe the doctor will be there to control the patient and the engineer to calculate trajectories and understand anatomical points.

9. **What do you consider being the main challenges caused by the implementation of these technologies?**

   The challenge will be the economic side, there's a lot of technology that we don't have access to, the investment is rare. Before investing in that there is a lot of important and basic thing to do before.

   For the private sector might be easier but the patient won't want to pay extra for it.

10. **(a) How are measured and tracked the following aspects?**

    - **success rate**
    - **productivity**

    At my last hospital, in Coimbra, we would review mortality rate and morbidity of the different sub areas, using data from the hospital (3 in 3 or 6 in 6 months). Only the director would pay more attention to the productivity.

    But it is hard to define success, surgery is not objective, if we take the tumor but the patient won't be able to move one arm, is that success?

    (b) How do you think the implementation of these technologies will impact those same aspects?

When we use something new in the OR we always need help, neuro navigation, electro physiology, they always have brought advantages to the patients.

11. **How do you think the implementation of these technologies will impact the surgical team's motivation?**

    For people who really like to do surgery it might reduce a bit the motivation because surgeries will become more boring, on the other hand results will be better what also might increase motivation.

12. **(a) What type of capacity building did you have to work with the present technologies?**

    During my intern years I've been doing practical and theorical courses, some in cadavers other in artificial models. They are paid by the surgeon, everything is voluntary, so we need to have some financial stability to invest in this.

    (b) What type of initiatives do you think should be implemented at hospitals to prepare surgical teams to work with new technologies?

    In the first place, it is necessary to show results, present clinical cases and studies, older neurosurgeons are always people more resistant to innovation, so it is important to show them that technological evolution can bring advantages to their patients. There should also be economics incentives to motivate the realization of courses and workshops, but also to have hospitals more open to the idea and buy these products, having people from companies to teach us how to work with the machine.

13. **How do you think education of future surgeons/interns should change taking into consideration the future of NS and new tools as augmented reality?**

    Education will improve a lot, nowadays we already have some courses developed with augmented reality, what reduces the need and cost in preparing cadavers. When we talk about less invasive methods, the surgical technique can be a bottleneck, what will be a down side, but the evolution will lead to that.

14. **How do you think education of medical students should change taking into consideration the future of NS and new tools as augmented reality?**

    The medical degree is still too based on what we call traditional medicine, what makes it not updated. Some universities have already included some courses in investigation

and technology, but it should become mandatory to have some courses about topics of biomedical engineering. Besides that, the way of learning will be different, studying anatomy can become more real with models in Virtual Reality, visualizing surgeries, increasing the sense of presence in surgeries. The evolution of medicine should lead to the necessity to think about the study plans, mainly in the introduction of new courses and ways of teaching.