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LABOUR SAFETY OF ROBOTIC SURGICAL DEVICES: RISKS ARISING FROM THE USE OF ROBOTIC SURGICAL INSTRUMENTS

ROBOTSEBÉSZETI ESZKÖZÖK MUNKAVÉDELME: ROBOTSEBÉSZETI ESZKÖZÖK HASZNÁLATÁBÓL SZÁRMAZÓ KOCKÁZATOK

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Abstract

Robotic surgery poses new challenges in the field of occupational health and safety, where it is necessary to identify the pathogenic factors and risks associated with robot-assisted surgeries. Our research was conducted by means of a questionnaire survey of surgeons and residents working at the largest healthcare, teaching and research university in Hungary and an ergonomic analysis for both robotic surgery and laparoscopic and conventional procedures. The results show that robotic surgery is more ergonomic than open or laparoscopic surgeries. Analyses of occupational risk factors in healthcare workers showed that the most common risk factors are ergonomic, psychosocial and biological risk factors. Ergonomic measures and the management of pathogenic factors are very important in robotic surgery, as they can optimise surgical performance and minimise health risks.

Keywords

occupational safety, ergonomics, occupational health protection, robotic surgery, occupational safety measures

Absztrakt

A robotizált sebészet a munkavédelem szakterületén új kihívásokat jelent, ahol azonosítani kell a robotasszisztált műtétekkel kapcsolatos kóroki tényezőket és kockázatokat. Kutatásunk Magyarország legnagyobb egészségügyi ellátó, oktató és kutató egyetemen dolgozó sebészek és rezidensek kérdőíves felmérésével és az ergonómiai elemzéssel történt mind a robotsebészeti, mind a laparoszkópos és hagyományos eljárásokhoz. Az eredmények azt mutatják, hogy a robotsebészet ergonomikusabb, mint a nyitott vagy laparoszkópos műtétek. Az egészségügyi dolgozók munkahelyi kockázati tényezőinek elemzései azt mutatták, hogy a leggyakoribb kockázati tényezők az ergonómiai, pszichoszociális és biológiai kockázati tényezők. Az ergonómiai intézkedések és a kóroki tényezők kezelése nagyon fontosak a robotsebészetben, mivel optimalizálhatják a sebészeti teljesítményt és minimalizálhatják az egészségügyi kockázatokat.

Kulcsszavak

munkavédelem, ergonómia, munkahelyi egészségvédelem, robotsebészet, munkabiztonsági intézkedések

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INTRODUCTION

Robotic surgery is the most advanced technology of the 21st century. In the field of occupational health and safety, it is necessary to identify the causal factors and risks associated with robot-assisted surgery, as well as the occupational safety measures and consequences of the coronavirus pandemic and medical gases used in healthcare. [10][11] Since robot-assisted surgery improves the effectiveness of medical interventions in terms of successful surgical outcomes and patient recovery, it is very important to create an appropriate working environment and ergonomics, ensure the availability of occupational safety equipment and reduce psychosocial risks.

LITERATURE REVIEW

Medical robots facilitate surgeries, simplify clinical processes and hospital logistics, and improve patient care and workplace safety. [1] For example, tissue damage, bleeding, complications, duration of surgery, length of hospital stay and time off work. The introduction of laparoscopic surgical techniques greatly reduced these risks, although this technique made it difficult or impossible to access certain areas, and the cameras used only provided a two-dimensional image of the surgical site.

Industrial robots became widespread in the 1980s. In the mid-1980s, brain biopsies were performed under CT guidance using a modified PUMA-560 industrial robot. In the United Kingdom, the PROBOT robot was developed to perform prostate surgery through the urethra, which allowed for the reconstruction of the prostate and the proper removal of the organ. Prostatectomy was thus considered the first robotic surgery, and in the late 1980s, Integrated Surgical Supplies developed the Robodoc robot specifically for hip replacement surgery. [2]

In the 1990s, robotic surgery and the tools necessary for its wider application were further developed. Robotic abdominal surgery became possible with the introduction of Computer Motion AESOP (Automatic Endoscopic System for Optimal Positioning). AESOP was a robotic arm that allowed surgeons to control the orientation of a conventional laparoscope using foot pedals and voice commands. Four years later, Computer Motion introduced the second-generation Zeus robotic system, which was the first robotic system to offer instrument control in addition to camera control. Zeus consisted of three robotic arms (one for 2D laparoscopy and two for controlling surgical instruments). The camera was controlled by voice commands similar to those used for AESOP, while the surgeon controlled the manipulators from a remote console. The computer translated the surgeon's movements to the laparoscopic instruments; the Zeus system had the same 2D video screen as the laparoscope. [2] Using the Zeus robotic system, surgeons in New York performed the first remote robotic in situ surgery, a cholecystectomy on a patient in Strasbourg. A special optical network was used for this surgery, and several similar transatlantic surgeries have already been performed on pigs. Remote surgery was limited by bandwidth and cost; while ZEUS was under development, Intuitive Surgical introduced the da Vinci robotic surgical system. The da Vinci Surgical System is the most sophisticated robotic surgical system; in March 2006, the first remote surgery using the da Vinci robotic system was performed via the public internet between the , University of Cincinnati, and Intuitive Surgical in California. [2] Robots are now used not only in operating theatres but also in clinical settings

to support healthcare professionals and improve patient care. During the COVID-19 pandemic, for example, hospitals and clinics introduced robots to perform a wider range of tasks in order to reduce exposure to pathogens. [1] [10]

METHODOLOGY

The research was conducted at the patient care unit of Hungary's largest healthcare, teaching and research university. Data collection was carried out through an on-site visit to a clinic using a robotic surgical device, observation of surgery, review of occupational safety documentation, and a questionnaire survey. The on-site visit took place on one occasion, where a qualitative survey and interviews were conducted with the doctors operating the robotic surgical device and the staff assisting during preparation and surgery. In addition, a questionnaire survey was conducted with seven doctors on the use of the robotic surgical device and a comparison of traditional surgical and laparoscopic procedures. The results of the questionnaire survey were compared with the results of international research. During the review of occupational safety documentation, 200 pages of professional material were reviewed.

CONCLUSIONS

The growing popularity of robotics constantly poses new challenges for occupational health and safety. Working with robots must always be considered from an occupational health and safety perspective as they evolve. In many cases, people still need to adapt to the possibility of working with robots. In the coming years, robot-human collaboration will take on increasingly diverse forms, robots will become more autonomous, and human-robot collaboration will take on entirely new forms. Existing approaches and technical specifications for working with robots, which protect workers from task-related risks, must be continuously reviewed.

Introduction to robotic surgical tools

Doctors use a variety of technologies to extend their capabilities beyond the human body. Magnetic resonance and computer tomography scanners, for example, allow doctors to see inside the body. Similarly, many surgeons use the da Vinci system to perform robotic surgery. [3]

Intuitive, a pioneer in robotic surgery and manufacturer of the da Vinci surgical system, was founded in 1995. [4] The first da Vinci system, a special surgical robot designed for minimally invasive surgical procedures, was launched in 1999. A fourth surgical arm was added in 2003. The latest version, the da Vinci Xi model, was released in 2014; according to Intuitive, the Xi offers improved functionality compared to previous models and is optimised for complex procedures. [5]

Today, da Vinci continues to develop and improve its robotic systems, enabling surgeons to expand their capabilities. [4] The da Vinci robot is not an automated surgical system, but a teleoperative tool for the specialist, who usually sits directly next to the robot in the operating theatre with the patient. The main advantage of the da Vinci system is that the specialist can use smaller robotic instruments that require smaller incisions, as well as visual enhancements such as thermal imaging, which provide valuable information that is

not available to the human eye alone. [5] The da Vinci vision system provides high-resolution three-dimensional imaging, giving the surgeon a clear view of the surgical site magnified ten times larger than the human eye.

The da Vinci surgical system consists of four arms equipped with interchangeable surgical instruments. One arm is typically equipped with a camera, while the other arms are equipped with instruments such as scalpels, graspers, cauterisers and staplers. [6] Surgeons use small instruments that move like the human hand, but with a much greater range of motion. The system's built-in tremor filter technology allows the technician to move all instruments smoothly and accurately. The da Vinci system translates the surgeon's hand movements to the console in real time and performs the bending and rotation of the instruments as the procedure progresses. The small articulated instruments move like the human hand, but with a wide range of motion, allowing for very precise surgical manipulation [4].

Figure 1: Structure of a robotic surgical instrument [6]

The da Vinci robot is also equipped with haptic feedback: early models vibrate when the software detects a collision, while newer models give a similar signal if the surgeon moves too quickly or moves outside the field of view. The ergonomic console also ensures the comfort of the surgeon's body. They no longer have to crouch over the operating table for hours. [6] Doctors at Semmelweis University say the following about the surgical robot and its capabilities: "With this robot and this application, we will be able to reliably apply the most advanced surgical techniques." Robotic surgery will play an important role, especially in cancer surgery. For the patient, a significant advantage of the robotic surgical device programme is that the movements performed by the surgeon will be more delicate and precise, leading to a significant reduction in collateral trauma. This significantly reduces recovery time, time spent in intensive care and the need for blood transfusions. The device has seven degrees of freedom, allowing it to move its arm through 520 degrees. As a result, areas that were previously very difficult to reach with open surgery, and sometimes even with laparoscopy, are now easily accessible. The system consists of three main parts. The part that comes into direct contact with the patient is the robot itself, which in this case has four arms. Next to it is a surgical console through which the surgeon communicates with the robot's body and performs the surgery. The third part contains all the equipment necessary for the surgery, including screens and displays, as well as a high-frequency cutter that ensures surgical safety and haemostasis.

A surgeon sits at the surgical console. What could only be seen in two dimensions during laparoscopic surgery can now be seen in three dimensions. The resolution starts at 10x magnification and can be increased from there. Furthermore, as it can be controlled with the fingers, it allows for greater freedom and finer movements. This is a special device with two consoles. There are not many of them in the world, as universities are educational institutions that train doctors and medical graduates. Robotic surgery is divided into the five stages shown in the figure below, with the main focus on robot preparation and use. Each stage has a starting and ending point and involves one or more tasks.

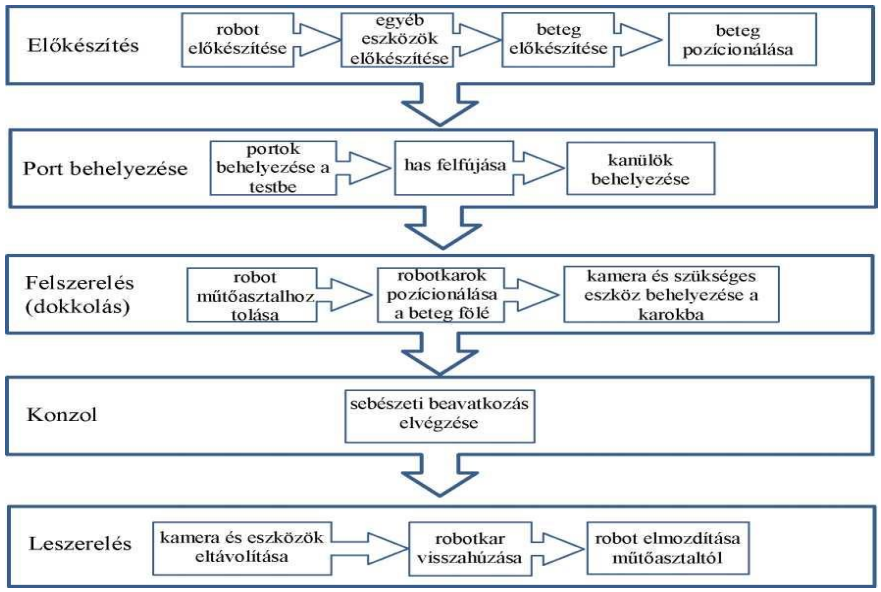


Figure 2: Phases of the robotic surgery procedure. 15]

Processes:

Preparations - During the preparation phase, the assistant performs four tasks, including preparing the robot and positioning the patient on the operating table. Anaesthesia begins after induction of anaesthesia and ends immediately before the first skin incision. This includes preparing the robotic equipment, other surgical instruments and the patient.

Port insertion - During the port placement phase, the surgeon, with the help of an assistant, inserts the cannula into the patient's abdomen and inflates the abdominal cavity to ensure working space. It begins with the initial skin incision and ends when all cannulas are in place and the robot is ready for docking.

Equipment - The preparation phase is divided into three steps: (1) moving the robot from the corner of the room to the operating table; (2) positioning and securing the robot arm to the patient's cannula; and (3) inserting the instruments and cameras into the robot arm. This begins when the team member first starts moving the robot towards the operating table. It ends when the camera and the last instrument are properly secured to the robotic arm and connected to the patient's cannula. These tasks are performed by the surgeon and assistants.

Console - Once the robotic arm is in place, the surgeon walks over to the robotic console in the operating theatre, sits down, and begins the operation. The surgeon usually works alone. For example, he or she changes instruments, cleans the camera, or performs suction. It begins when the surgeon first sits down at the console, announces that the surgeon has finished, and ends when the surgeon steps away from the console.

Dismantling - At the end of the operation, the robotic arm retracts and the assistant places the robot in a corner of the operating theatre. Figure 3 shows the area of the operating theatre where the surgeon and assistant work.

Figure 3: Operating theatre with robotic surgical equipment (source: author's own work)

The workflow analysis provided an overview of the tasks required for robotic surgery. Five stages of robotic surgery were identified to describe the typical steps of robotic surgery. The surgical team works to achieve goals related to safety, timeliness, sterility, resources, roles, and location. However, the order and emphasis of these goals may vary depending on the culture of the operating theatre. [7]

Identifying and assessing risks

Prolonged surgery causes eye strain. Looking at the monitor during surgery can cause discomfort, which has a negative effect on the surgeon. When surgery is performed with the aid of a surgical robot, the surgeon controls the robot from a surgical console, while an assistant monitors the operation on an external monitor. e concentration on the display can cause eye fatigue. Since the work takes place in a virtual space, this can easily lead to headaches and is very dangerous in this profession, as it affects concentration, accuracy and attention stability. In addition to the above complaints, working with monitors often causes dry eyes, which can also be uncomfortable. Dry eyes refer to the inability of the eyes to produce and maintain sufficient quantities of quality tear fluid.

Since the eyes and head are reflexively connected, any tension or discomfort in the eyes can spread to the head and neck, causing headaches. The combined effect of these factors can lead to errors, reduced work efficiency and stress, all of which must be taken into account from a health and safety perspective. Although surgical procedures require great effort on the part of the surgeon performing the operation, factors other than the use

of surgical robots also influence the physician's performance. During surgery, the physician controls the robot and the robotic arm via a console, but is not directly present at the surgical site. Poor coordination between surgical instruments and a lack of three-dimensional spatial awareness can cause additional stress. The need to deal with unforeseen situations can be stressful even for experienced surgeons. When workers are already stressed, it is difficult for them to concentrate and think. Problem-solving skills may decline and reaction times may increase. Since the robotic arm has no sensors, the surgical team must be fully aware of the robotic arm and its movements. The use of robotic surgery does not negate the importance of teamwork. Poor communication or disruption of teamwork can lead to morbidity. Inadequate flow of necessary information can also lead to surgical errors and complications.

New procedures and learning processes can place a significant psychological burden on clinicians. Starting to use new instruments or working with new instruments is a significant psychological burden until it becomes routine. This morbidity factor can be significantly reduced through training and simulation exercises in which doctors participate before performing the actual procedure. In addition, after training, the patient must undergo an examination, the success of which determines whether the surgeon will subsequently be authorised to perform the procedure. Although only indirectly related to the robotic surgical procedure, an appropriate working environment is also important. Proper lighting is key to preventing eye strain and fatigue during surgery. The proper placement of monitors is also important. If the monitors are not positioned at the correct height, it will be difficult to follow the surgery, which will affect image clarity, visibility and perception. Every member of the team must be able to monitor what is happening. The role of the surgeon's hands is taken over by the robotic arm, so the same regulations that apply to the surgeon's hands and the surgical instruments used also apply to the arm and the instruments it contains. There is also a risk of droplet infection if the doctor and the robot control centre are in the same operating theatre as the patient. Surgical instruments must be handled and disinfected in the same way as in normal medical procedures. Care must be taken to ensure that disposable instruments are used for their intended purpose. Surgical instruments must be cleaned and disinfected in accordance with safety regulations, as damage to surgical instruments poses the same risk to the outcome of the operation. It is also important that the surgical instruments on the arm are properly secured. At the start of each operation, the correct functioning of the surgical robot must be checked, for example, the correct functioning of the arm and the correct securing of the instruments.

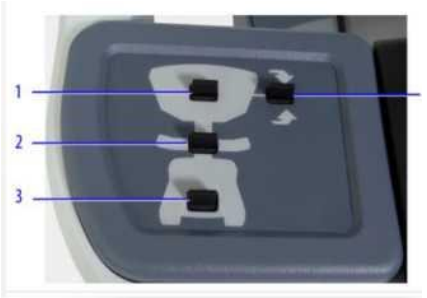
Ergonomics

In this context, the machine-human relationship is the relationship between the robot and the surgeon controlling it, and the work environment is the operating theatre. However, it is not only the surgeon who is present in the operating theatre, but also the assistants working alongside the surgeon. While controlling the robot, the surgeon continuously monitors the progress of the operation in a virtual space. Therefore, the surgeon sits for several hours watching the 3D display (Figure 14). In the case of long operations, the doctor spends a considerable amount of time watching the events unfold with his head in front of the 3D display. This part of the control centre, where the doctor

observes events taking place in 3D space, must be ergonomically designed to provide comfortable head support.

Figure 4: 3D viewing display of a robotic surgical device [12]

It is also important that they are at the correct angle and height adjustable, but even so, it can be difficult for the neck after a while if the head is held at a constant angle. Lack of blood circulation can lead to headaches, numbness and pain. In addition, keeping your head in the same position for a long time while looking at the 3D display can cause discomfort in the forehead area. It is important that the surface is easy to clean, yet soft and flexible. During surgery, doctors sit in the same position, which puts a lot of strain on the spine and skeletal muscles and requires great physical effort. The surgeon's seat must also be ergonomically designed so that the doctor can sit in the correct posture. The adjustment options for the surgical console are shown in Figure 5.



1. 3D viewer height
2. Armrest height
3. Foot switch panel depth
4. 3D viewer tilt

Figure 5: Robotic surgery console adjustment options [13]

Surgeons experience high levels of mental stress during operations. Headaches or back pain during surgery can affect the outcome of the surgical procedure. Risk factors must always be taken into account because lives are at stake. Incorrect posture during surgery can lead to health and musculoskeletal problems later on. When using robotic surgical

technology, the hands and fingers are also subjected to increased stress, as the robot's arm simulates the surgeon's movements and provides the working surface for the arm.

Figure 6: Surgical console control options [14]

Surgical robots performing operations have multiple arms, so there are multiple control panels and consoles in the work area. Since doctors operate these panels and consoles throughout the operation, ergonomic design and placement are very important. If not designed properly, the controls will be uncomfortable and fingers and hands will tire quickly. The controls must be easy to operate, and the forces applied must not exceed the dynamic and static loads permitted on the surgeon's operating limb. It is important that they are designed so that the surgeon can distinguish them by touch without moving his head. Supports designed to rest the surgeon's hands and facilitate the holding of instruments should be comfortable and designed to enhance comfort. 's poor ergonomic settings can lead to: - incorrect posture - uncomfortable working position - numbness in the hands - insufficient blood circulation in the fingers - hand fatigue The surgeon controls the pedals with their feet, and their adjustment can also have a significant impact on the quality of work. The pressure surface, shape and size of the pedal have a significant impact on the ease and comfort of using the foot and pedal. The surface and width of the foot pedal should be such that the foot can rest comfortably on it. The pressure surface should have a suitable non-slip surface to prevent the surgeon's foot from slipping during surgery. Ergonomic considerations and the management of pathological factors are critical in robotic surgery in order to optimise surgical procedures and minimise health risks.

Comparison of research results

The above results are confirmed by international research, such as a survey conducted by Sara Monfared and her colleagues, in which 20 surgeons and surgical trainees analysed 29 robotic and 48 laparoscopic procedures. After the laparoscopy, numbness in

the right finger and stiffness in the right shoulder were observed, as well as irritability in the surgeon, while after the robotic surgery, increased back stiffness was observed. The aim of the study was to compare the ergonomic risks between surgeons and surgical trainees performing robotic and laparoscopic procedures. Robot-assisted surgery resulted in lower postoperative discomfort and muscle tension in both upper limbs, especially on the surgeon's dominant side, but compared to laparoscopy, it increased static neck position with subjective back stiffness. These recognised ergonomic differences between the two platforms can be used to develop preventive measures. [8]

The analysis conducted by Ian Jun Yan Wee and colleagues included 29 articles. Studies using objective measurement tools showed that robotics offers significant ergonomic advantages and reduced workload compared to laparoscopy for both surgeons and trainees. Survey studies also showed that self-reported discomfort was lower during robotic procedures than during laparoscopy and open surgery. Robotic surgery is ergonomically superior to open and laparoscopic surgery. However, the level of physical exertion remains significant and should be addressed through formal ergonomic training and proper familiarisation with the console. [9]

CONCLUSIONS AND RECOMMENDATIONS

Simulation and practical training should be at the centre of training, as this can provide surgeons with a routine that can prevent musculoskeletal disorders and reduce potential stress and psychological strain. Staff should be routinely trained in correct posture and the adjustment of the surgeon's console during surgery. Warm up before surgery (fingers, wrists, shoulders and hips) and, for longer surgeries, perform various exercises for the hands, arms and hips. Drink water regularly during surgery (sometimes coffee during longer surgeries). After a complex operation, the patient must be allowed to rest and recover mentally before moving on to the next patient. Well-thought-out work schedule: scheduling of operations (taking into account the number, complexity and duration of operations); sufficient quantity and quality of rest time for recovery.

SUMMARY

Our lives and work – whether in an office, industrial or medical setting – are often unimaginable without interaction with machines. In many cases, machines facilitate human tasks, but the right balance between humans and machines must be found. Ergonomic considerations and the management of pathological factors are very important in robotic surgery, as they can optimise surgical performance and minimise health risks. Regular expert evaluation, appropriate training, education and continuous improvement of techniques can all contribute to improving the ergonomics of robotic surgery. The aim of our research is to confirm the risk factors I have identified and to identify the health risks they pose. The risk factors involved are closely related to the work environment, as the occurrence of risk factors is strongly influenced by the work performed by the employee, the work process, and the tools and materials used during the work. Analyses of occupational risk factors for healthcare workers have shown that the most common risk factors are ergonomic, psychosocial and biological risk factors.

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