Competition on the medical robotics markets for elderly

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ABSTRACT

Population aging becomes one of the most significant 21st century social challenges. These challenges strongly reflect on the industry, labor, and financial markets. Population aging increases the demand for medicines, diagnostic equipment, and medical services. Both developed and developing countries have problems resulting from the current shortage of health workers and a limited supply of medical equipment. An alternative for medical staff growth is the robotization of medical services. However, robotics is economically justified when the costs of medical robots are lower than the construction of additional medical clinics and the increase in medical staff. Medical robotics appeared on the market later than the industrial and military ones but has recently found increasing use in high-income countries. Low and middle-income countries could not acquire expensive medical robots in sufficient quantities. The increased competition in the medical robotics market will lead to price reductions and make robotized services available for wide use. The article analyses the competition in segments of the medical robotics markets, connected with population aging.

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1. INTRODUCTION

The world's population of aging increasing in proportion of older people is observed in almost all countries. The process of population aging has become one of the most significant socio-economic problems of the 21st century. Population aging influences product, labor, and financial markets, as well as the medicine and social protection of the population. Many countries will face important health, pension, and social protection challenges in the coming decades because the number of people in the 65+ age group grows at a faster rate than other age groups. In the period 2019 and 2050, the number of persons aged 65+ globally is projected to more than double, while the number of children under five is projected to remain relatively unchanged. By 2050, a sixth person in the world is projected to be over 65 years old (16% of the population) up from one in 11 in 2019 (9% of the population), and this age group will include one of four persons in Japan, Europe, and North America [1]. Similar stages of population aging, but with some time lag, take place in Russia, China, and other countries of the world [2], [3].

Improvements in health care and social circumstances have resulted in an increase in life expectancy. Unfortunately, not all old people have good health: some of them suffer from multiple, interacting health problems. Health problems increase with age and go beyond what disease alone can capture, such as impairments in cognition, mood, and physical performance. Medical care aims to promote active, productive, and healthier lives for older persons. The existing demographic and social trends rely on the progress of technology, science, and medicine. The health systems should include diagnostics, prevention, treatment, and rehabilitation available for older persons' needs [4].

In the first turn, the population aging depends on demographic factors (fertility and death rates), the number and quality of medical institutions and medical staff, the availability of medical services, and the social security of older people (pensions, social assistance, nursing homes). Since the middle of the 20th century, almost all regions of the world have recorded a significant increase in life expectancy due to a decrease in mortality rates in older age groups along with a decrease in fertility. Although these indicators are key factors in the population aging around the world, international migration also leads to a temporary change in the age structure of the population in a number of countries without changing the overall trends [5].

The end users of medical services are patients suffering from certain diseases. As medical statistics show, many diseases are associated with aging [6]. The increase in the number of elderly people it makes necessary to increase medical facilities and health workers. The World Health Organization (WHO) estimates that there is a shortage of more than four million health workers needed to deliver essential health services and has called for immediate action to resolve the accelerating shortage in the global health workforce. The shortage affects developed and developing countries, but the latter worldwide suffer disproportionately not only because they have a much smaller workforce but also because their needs are so much greater [7]. Compounding this shortage for the most vulnerable countries is the phenomenon of healthcare worker migration. Both developed and developing nations are struggling to alleviate the huge challenges resulting from the current shortage of health workers and medical equipment coupled with increasing demands and diminishing supplies of healthcare providers [8], [9].

An alternative to this trend is the development of the medical equipment market and medical robotics. According to the Medical Design and Outsourcing (MDO) annual report there were 66 medical device companies worldwide with revenues over $1 billion and another 34 companies with revenues over $100 ml in 2021 [10]. In addition, about 400 companies are engaged in the production of industrial and service robots in the world medical market. Some of them are current or potential participants in the medical robotic markets. Along with large companies, small companies, and startups operate in the medical robotic market producing robot components, software, and mechatronics. Some integrator companies assemble robots from ready-made components according to customer requirements. Such individual robots cost the customer more than finished robots. Many startups in technical universities create new medical robot prototypes and look for an investor or a large company for mass-manufacturing.

The key propelling factors for the supply growth are the advantages offered by robotic-assisted surgery and robot-assisted rehabilitation therapy, and technological advancements in robotic systems, such as three-dimensional (3D) imaging, microscopic video cameras, data recorders, motion sensors, remote navigation, and others. A key restricted factor for demand growth is the relatively high price of medical robots, especially for poor countries. A set of equipment for radiation surgery CyberKnife costs $4 to 7 million. The price of surgical systems da Vinci is $1.5 to 2.5 million. Orthopedics robotic systems cost more than $0.5 million. Rehabilitation robots cost $80,000 to 100,000. Social assistance robots cost lesser. In addition, the annual maintenance cost of a surgery robot is about $125,000, which further adds to the already high cost of robotic surgery.

There are three aspects of using robots in medicine: medical (improving the quantity and quality of medical services), technical (developing new sensors, artificial intelligence programs, and medical instruments), and economic (reducing the price of medical robots, making them affordable for low-income and middle-income countries). The purpose of this article is to analyze the main economic trends in the use of medical robots, which can reduce the burden on medical institutions and medical personnel caused by the general aging of the world's population.

2. LITERATURE REVIEW

Technological and medical advances prevent aging and enable new opportunities for the active, productive, and healthy lives of older people. Healthcare systems have to maintain health, prevention, treatment, and rehabilitation that meet the needs of this population group. Modern enterprises with their automation and robotization of labor-intensive operations, as well as the possibility of online work and part-time employment, allow people of retirement age to continue working. In addition, policies for economic activity and social protection of older people should contribute to their longer, healthier, and better life quality. The development of medical robotics is based on the technological advances of recent years in the field of new materials, miniature power supplies, sensor devices, and artificial intelligence. These advances allow for the development of medical robots with increasing levels of autonomy and consideration of legal, ethical, and technical challenges [11].

Until the middle of the 20th century, robots were relatively expensive, and labor was cheap. Therefore, robots had limited application even in developed countries, since harmful and not requiring high-skilling manufacturing could be transferred to developing countries. However, in the world, there are constant multidirectional trends of decreasing prices for robots and increasing labor costs [12]. Robots are increasingly used in various sectors of the economy in many countries. Robotics has become an independent industry, including hundreds of large, medium, and small enterprises. Many universities have robotics departments. National robotics associations coordinate by the International Federation of Robotics (IFR), established in 1987 as a non-profit organization. The IFR regularly releases annual reports analyzing the various industrial and service applications of robots, in particular, the positive impact of robots on the quality of life [13].

The IFR classifies robots into industrial and service robots in accordance with the division of the economy into two sectors: manufacturing and services. In turn, service robots are divided into two segments: professional and household (consumer) robots. Most professional service robots in recent years have been sold for logistics purposes, which is largely facilitated by the development of the e-commerce market. However, logistics robots are used not only in the giant stores of online retail companies but also in hospitals to deliver medicines to patients. Similar robotic assistants are increasingly used in medical institutions for cleaning and disinfection. The other largest segment of the medical robotic market is assistants to medical staff for performing surgeries and rehabilitation [14].

Increasing hygiene requirements due to the coronavirus disease (COVID-19) pandemic resulted in sales of medical robotics up to 55% of the totally professional service robots' turnover in 2020. The retail sales of professional floor cleaning robots are expected to grow by double-digit rates on average each year from 2021 to 2024 [15]. Over the past decades, robotic-assisted surgery has appeared in many countries and rapidly spread to many surgical specialties. Robot-assisted systems are being routinely used to perform surgery, resulting in shorter recovery times and more reliable outcomes in some procedures. Robotic rehabilitation systems are successfully delivering physical and occupational therapy, enabling a greater intensity of treatment. Social-assisted robots allow the old person with physical disabilities to continue independent living in their own homes, perform simple tasks such as personal toileting and getting out of bed, and delay the transfer to a nursing home. They also greatly reduce the probability of isolation, depression, and loneliness [16].

Robots help to solve pressing economic problems, such as the scarcity of qualified personnel in clinics and elderly care. Robotization is the next step in economic development when the employee "transfers" to robots the execution of many monotonous jobs such as cleaning and disinfection of clinics and the lack of nurses. Medical robotics has a perspective for surgical interventions, rehabilitation, and help for aging people in daily living tasks. Although the main focus is on robotic systems for surgery, rehabilitation, and assistance robots also are increasingly being used [17].

Based on the most cited papers in this area, Dupont *et al*. [18] identified eight key research topics in the field of medical robotics. The development of physical and technical technologies has had a huge impact on medicine. Today, surgeons can perform operations that a few years ago seemed impossible. Such progress in medicine is caused by many factors. Firstly, modern clinics are equipped with the latest robotic systems, which allows for performing operations more accurately and with less risk to the patient's health. Secondly, advanced training programs for surgeons and their assistants permit them to perform operations using various robotic systems [19].

Medical robots perform better medical outcomes by competing with pharmaceuticals, gene therapy, and innovative hand tools. Many medical robot prototypes are created in the laboratories of technical universities around the world. Medical robotics resolves real problems in healthcare, including the problems of aging and improving life quality [20]. Micro and nanorobots have great prospects in medicine due to their advantages in targeted drug delivery to a diseased organ, precision surgery, medical diagnostics, and detoxification. The future success of this direction in medicine has arisen due to the close cooperation of specialists in the field of robotics, medicine, and nanotechnology [21].

3. METHODOLOGY

This study is based on a case study methodology that approaches the quantitative analyses of complex or uncertain results [22]. The article used data from reports of international organizations and consulting companies, annual reports of medical device companies, robotics subsidiaries, and relevant scientific publications. The aim of the research is to establish the monopolization degree of the robotic market segments related to the treatment of the elderly and the possibility of reducing prices for robots due to increased competition. The research included four segments: robotic general and special surgery, robotic orthopedic surgery, robotic postoperative rehabilitation, and social robots.

4. RESULTS

4.1. Medical robots for old people

The use of robots to treat people began to develop about 30 years ago. Now the manufacturing of medical robots is one of the most advanced and fast-growing segments of the digital technology market. Medical robots gradually become habitual medical assistants. All over the world, medical robots are actively used in many areas. Among these areas, we select four markets that are most helpful in resolving the problem of population aging: robotic general and special surgery, orthopedic surgery, rehabilitation robotics, and nursing robotics that assist in servicing elderly patients. Here is a brief description of these markets.

General and special robotic surgery is a very promising area of robotics, which began with modified industrial robots, but now has turned into a dynamically developing segment of medical robotics. Orthopedic robotic surgery is designed to perform operations on the musculoskeletal system including operations on the hip and knee of elderly patients. Rehabilitation robots are designed for postoperative recovery of the musculoskeletal system functions after a stroke and other age-related diseases (partial loss of vision, Alzheimer’s disease, and other serious diseases). Although not all bionic prostheses and exoskeletons can be considered classic robots, they are complex mechatronic systems, and this segment occupies an important place in the recovery process after an illness or surgery. Assistance and social robots are designed to solve the tasks of premises’ cleaning and disinfecting, transportation of patients, medicines, and other goods inside hospitals and nursing homes, as well as caring for elderly patients with limited mobility.

4.2. Segment of general and special surgery robots

Robotic surgery began later than industrial robots with their modernization, but from that moment it received its own development and currently shows not only the best therapeutic effect in certain surgical operations but also has become the largest segment in medical robotics [23]. The technical aspects of modern robotic-assisted surgical systems with a detailed description of their configurations, actuation schemes, and control approaches are discussed in a scientific article [24]. Robotic surgical systems allow a surgeon at a console to operate remote-controlled robotic arms, which may facilitate the performance of laparoscopic procedures.

The American company Intuitive Surgical (IS), founded in 1995, dominates the market for robotic general and special surgery and occupies more than 90% of the market, i.e. this segment is close to a monopoly. The company is a pioneer in the area of robotic minimally invasive surgery. It develops, manufactures, and sells da Vinci robotic systems and tools, and provides training specialists for working with this system. Structurally, IS consists of one division. According to the IS Annual report in 2022, the company manufactures more than 1,264 da Vinci systems (591 units transfer to clinics under operating leasing). For the entire period of its activity, the company supplied 7,544 of these systems, including 4,563 in the USA, 1,388 in Europe, 1,234 in Asia, and 359 in the rest of the world.

In 2022, more than one million surgeries were performed on da Vinci devices in the USA alone (an average of about 250 surgeries per system). Approximately 10% of surgical procedures in the USA are performed using robots, while in other countries this number is significantly less. The growing popularity of surgical robots can be evaluated by the change in the IS revenue, which has grown more than 2,5 times since 2013, as shown in Figure 1. At the same time, 84% of the total revenue was provided by selling da Vinci systems and accessories, and the remaining 16% came from training, maintenance, and lease payments. Figure 1 shows the IS revenue growth slowed down in 2020 due to the impact of COVID-19, but already in 2021, sales and revenue growth recovered.

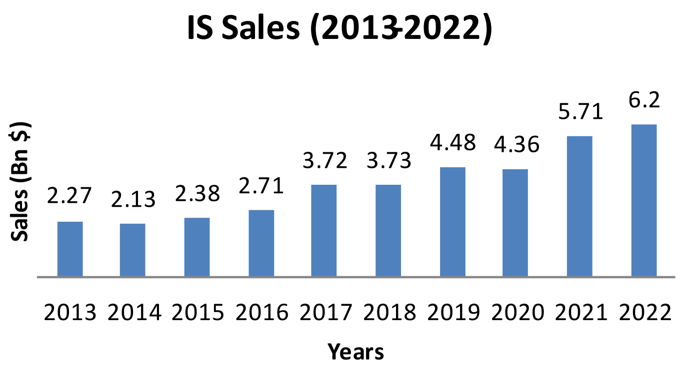

Figure 1. Intuitive Surgical Revenues (in billion dollars) 2013-2022 (based on IS AR database)

Da Vinci surgical systems are comprised of the following components: a surgeon's console, a patient-side cart that holds up to four electromechanical arms manipulating the instruments inside the patient, a 3DHD vision system, firefly fluorescence imaging and integrated table motion that coordinates the movements of the robotic arms with an advanced operating room. Some of the components necessary for the assembly of da Vinci systems are currently provided by monopolistic suppliers. The da Vinci robots cost $1,5 to 2,5 million, the Annual Maintenance Support adds another $100,000. It can be expected that the reduction in prices for surgical robotic systems, components, and consumables will occur as the competition will intensify in this segment of the robot market. The da Vinci robotic system has become a common method of general, urological, and gynecologic surgeries in developed countries, but its high price limits the use of robotic surgery in low and middle-income (LMI) countries [25].

In Germany, more than 100 clinics are equipped with da Vinci systems, and the price of a commercial operation using the da Vinci system is €2,000 [26]. Approximately 70 da Vinci robots were installed in mainland China at the end of 2019 (10 in Hong Kong), and a joint venture was established with IS for the promotion of the system to the Chinese market [27]. In 2021 there were 36 da Vinci systems installed in Russia, mainly in Moscow and St. Petersburg, and experience with this system has been accumulated. There were more than 4,000 surgeries (an average of 113 surgeries per system), which shows a lower efficiency in using the system compared to the USA and China [28].

The IS's main competitor is Johnson & Johnson (J&J), one of the American pharmaceutical giants, which received revenue in 2022 of $94.9 billion. J&J has three divisions: Medical Devices (MedTech), Pharmaceuticals, and Consumer Products. The MedTech segment includes a broad range of products used in the Surgery, Orthopedics, and Vision fields. One of its subdivisions (Verb Surgical Group) is currently introducing a new system for robotic surgery. J&J recently provided details about the new robotic system Ottawa, which is expected to compete with the da Vinci system. Clinical tests of the Ottawa system with six robotic arms are scheduled for 2022. After acquiring Auris Health with its Monarch system, J&J increased its share of the global surgical robotics market. Figure 2 shows that over the past decade, J&J's revenue growth has been significantly lower than IS's. However, the sales increased significantly in 2021-22, primarily driven by MedTech's segment.

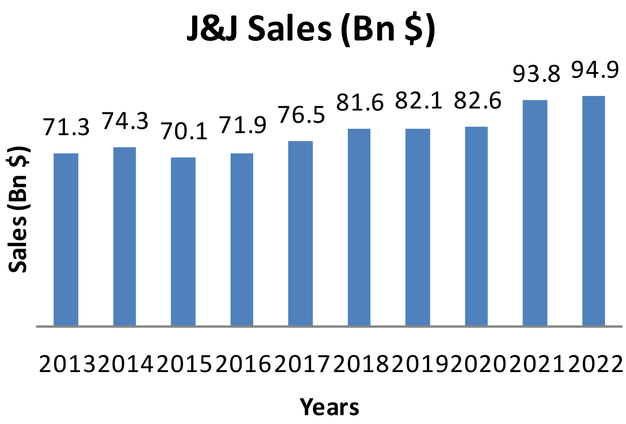

Figure 2. Jonson & Jonson Revenues in (billion dollars) 2013-2022 (based on J&J AR database)

Another potential competitor to da Vinci could be the Hugo RAS surgeon robot from Medtronic. Medtronic is a publicly traded American medical device company with annual revenue of over $30 billion in 2021. Structurally, it consists of four divisions, one of which (Medical Surgical) is engaged in the development and production of surgical robots. The Hugo Robotic Surgery System is used for the same type of minimally invasive surgery as da Vinci and works well with other Medtronic surgical equipment. It is used in clinics in the USA, EU, Canada, and Australia. This technique has not yet been delivered to Russia.

Small companies such as CMR Surgical (robotic system Versius), Asensus Surgical (robotic system Senhance), Medicaroid, Medrobotics Corp, and others introduced products in the field of robotic-assisted surgery or declared their efforts to enter this market. The Versius system is already operating in the UK, India, and Pakistan. It is more versatile in comparison with da Vinci and has independent modular arms. The system Senhance is assisted in the accurate control of laparoscopic instruments for visualization and endoscopic manipulation when operating surgeries. The system now is available for sale in the USA, the EU, Japan, Russia, and other countries. Companies with substantial experience in industrial robotics (Siemens, Philips, GE, KUKA) could potentially expand into the field of surgical robotics and become competitors for the IS. In addition, research efforts utilizing computers and robotics in surgery are underway at various technical universities and hi-tech companies.

4.3. Orthopedic surgery medical robot segment

The global orthopedic surgical robots market size was $1.2 billion in 2021 and is predicted to reach $6.5 billion by 2030, representing a CAGR of 20.75% throughout the period of 2021-2030 [29]. Robots as assistants to orthopedic surgery have been used in clinics for more than 20 years. They can provide surgeons (especially young and inexperienced) with better accuracy and reproducibility of results. Depending on the degree of automation, all orthopedic surgery systems can be divided into automatic systems, semi-automatic systems, and passive systems. According to their use in surgery, they can also be divided into navigation robots, guiding cutting robots, etc. Different types of robots suitable for different operations have their own advantages and disadvantages [30], [31].

The orthopedic surgery market includes both large players and innovative small companies that are acquired by large companies to optimize their businesses. The leader of this market is the American company, Stryker. The company has two divisions: neurosurgery and orthopedics. The Orthopedics Division (32% of the orthopedic surgery market) produces Mako robotic systems for knee and hip surgery. The revenue of Stryker in 2021 amounted to more than $17.1 billion, an increase of 19.2%. The sales of the orthopedic division showed a higher growth of 26% compared to 2020. The system Mako has already been installed in clinics in 28 countries and is the main growth driver for Stryker as a supplier of medical equipment, instruments, and system accessories. The 2019 purchase of Mobius Imaging and its subsidiary Cardan Robotic made Stryker a leader in the robotic spine surgery segment. Stryker products are sold directly to clinics in the US and other countries.

The second player in the robotic orthopedic market after Styker is the American company Zimmer Biomet Holdings (ZBH), whose main products are innovative medical equipment for operating on patients suffering from disorders or injuries of bones, and joints, and supporting soft tissues. The company also develops, manufactures, and sells orthopedic reconstructive products, sports medicine products, biologics, limb injury treatments, and other surgical products. ZBH's flagship robotic product, named ROSA, is a multifunctional system that assists surgeons during knee, hip, and spine surgeries. The system already is used in more than one hundred clinics in Europe, the USA, Asia, and the Middle East. ZBH showed even more modest revenue growth compared to Styker [32].

The British company Smith & Nephew (S&N) manufactures medical equipment for orthopedic surgeries, arthroscopy, and more. The orthopedic segment includes an innovative range of hip and knee implants used to replace diseased, damaged, or worn joints, and robotics-assisted and digital enabling technologies. In the summer of 2020, S&N announced the delivery of a new generation Cori surgical system with a portable modular design. It is a portable surgical system that uses new bone milling technology and simple software.

Figure 3 shows that the Styker, ZBH, and S&N sales ware grown more slowly in the last decade than IS's because of stronger competition in the orthopedic market. The above three leading companies occupy more than half of the orthopedic market (Styker-32%, ZBH-20%, and S&N-11%). The sales dropped in 2020 due to the impact of COVID-19, but already in 2021, sales and revenue growth recovered.

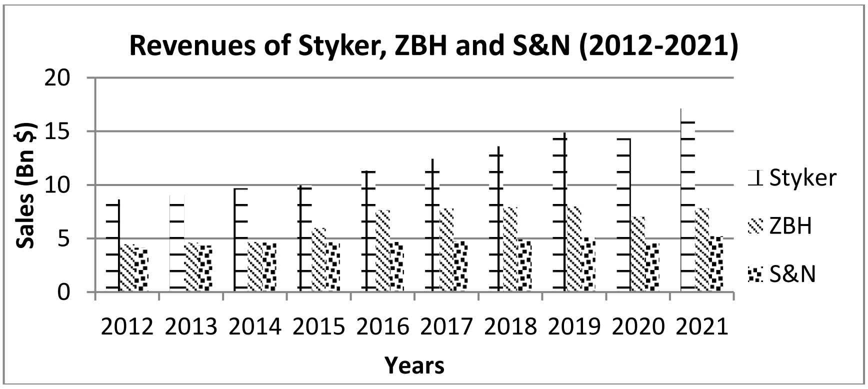

Figure 3. Styker, ZBH and S&N Annual Revenues (in billion dollars) 2012-2021 (based on Styker, ZBH and S&N AR database)

The J&J has an orthopedic subdivision of MedTech (DePuy) that designs, manufactures, and distributes products for reconstructing damaged or diseased joints and for repairing and reconstructing traumatic skeletal injuries. In 2012 J&J completed the acquisition of Synthes, which was integrated with DePuy to establish the DePuy Synthes Companies of J&J. In 2019 MedTech supplied the Orthotaxy robot that is much smaller and less expensive than surgical orthopedic robots currently on the orthopedic market. J&J currently occupies about 10% of the orthopedic surgery market.

Two Asian small companies show significant growth in the orthopedic surgery market. The Korean company Curexo acquired the medical robotics division of Hyundai Heavy Industries and launched the production of the system Robodoc. This system is used in knee and hip replacement surgeries. The Chinese company Tinavi is showing good growth and enjoys the Chinese Ministry of Science’s support. It manufactures robotic guided systems used in orthopedic surgeries. In 2010, Tinavi became the first Chinese manufacturer to obtain approval for an orthopedic robot.

The orthopedic surgery market is already quite competitive. This shows a more moderate growth in the revenue of companies operating in this market. However, the demand for orthopedic robots is quite high, since not only the elderly need orthopedic operations, but also the disabled from birth, war invalids, and victims of various kinds of accidents.

4.4. Rehabilitation robot segment

Many people suffer from injuries that require long-term medical rehabilitation. The rehabilitation process is complex, with psychological and physical dimensions, and outcomes are difficult to guarantee. Thus, these robots are being developed to help people with various medical conditions on their road to recovery. The stroke usually results in impaired gait, which affects functional ambulation and quality of life for elderly people. The robotic exoskeletons (RE) for walking on the ground are devices that are programmed to provide high load and special assistance for movement disorders, which offer new possibilities for the rapid rehabilitation of people after stroke, spinal, or musculoskeletal injuries [33], [34]. According to the Centers for Disease Control, there are approximately 800,000 strokes suffered per year only in the USA and approximately 15 million worldwide. The market for RE is very young compared to the markets described above and is just beginning to develop.

The Japanese robotics company Cyberdyne manufactures the exoskeleton Hybrid Assistive Limb (HAL), developed by Tsukuba University (Japan). The HAL is a robotic treatment device for the purpose of improving and regenerating the physical function of patients, welfare, and life support. The Cyberdyne revenue in 2021 was $17.6 million (a growth of 14.6% compared to 2020). The main markets for this company are Asian countries.

The American company Ekso Bionics develops and manufactures bionic exoskeletons (active exoskeleton EksoGT and passive exoskeleton Ekso Vest) for rehabilitation medicine. The Ekso Bionics revenue in 2021 was $11.2 million (a growth of 27% compared to 2020). The other American company ReWalk has developed and now sells two types of exoskeletons for persons with spinal cord injury (SCI) and paraplegia. Its revenue in 2021 was $6 million (a growth of 36% compared to 2020). This growth was driven by business conditions normalizing after the impact of the COVID-19 pandemic in 2020. The main markets for both companies are the United States and Europe.

The Center for Intelligent Mechatronics at Vanderbilt University (USA) designed, in 2010, a prototype of the exoskeleton Indego, that assisted stroke victims and other paralyzed or semi-paralyzed people to walk independently. The airspace control technologies manufacturer Parker Hannifin Corp (PH) is funding further development and manufacturing of the first commercial version of the exoskeleton. In 2018, the new Indego Therapy device replaced the existing three types of Indego Therapy Kits offered to hospitals and rehabilitation centers since 2016 and is now commercially available for customers in the United States and Europe. The results of Indego tests showed the efficiency of RE therapy with acute and chronic stroke of varying severity degrees [35]. The prices of exoskeletons are in Table 1.

Table 1. The most popular exoskeletons prices [36]

Type	Price	Notes
HAL	$20,000	Qualifying patients only
Ekso	$100,000+	clinics only
Indego	$80,000	
ReWalk	$77,000	

In May 2022, the Korean company Samsung Electronics sought approval from FDA for its assistive robot GEMS Hip, a wearable device that acts as an exoskeleton for users with mobility issues, using an active assist algorithm to improve gait and muscle movement. Also, in April 2021, the Japanese company Panasonic launched a mass production model of its walk training robot designed to provide safe and efficient walk training for elderly citizens, who have apprehensions about walking because of physical restrictions and the experience of falling. Thus, the high geriatric population and rising innovative product launches are expected to contribute to the growth of the rehabilitation robotic segment.

4.5. Assistance social robots' segment

Assistive social robots for interaction with humans play an important role with respect to the health and psychological well-being of the elderly. These robots are often combined under the common name "robotic nurses". The aging population needs more care than is available and robotics could promote the elderly population to maintain an independent life at home for as long as possible. However, it is difficult to be independent without assistance for physical and cognitive functions (i.e., there may be problems with walking as well as with remembering to take medicine). Mobility problems are the most important limitation for the elderly, and this problem increases significantly with age. Numerous studies demonstrate that very soon "robotic nurses" will not only be a solution to the problem of nurse shortage but will also become an important business in the robotics market [37], [38].

Kolstad *et al.* [39] presented experiences of integrating assistive robots in nursing care at three Japanese nursing homes through interviews and observations during 2019. The goal was to investigate and evaluate the current state of using robots within the nursing home, which involved firsthand experiences with real users (the elderly people and nursing staff). This study looked at experiences with the robots Pepper, Paro, and Qoobo.

Pepper is a semi-humanoid robot manufactured by SoftBank Robotics (one of SoftBank Group subdivisions) and designed with the ability to read emotions. Pepper's ability to recognize emotions is based on the detection and analysis of facial expressions and voice tones. SoftBank Group is a Japanese multinational conglomerate holding company that focuses on investment management (revenue in 2021 is more than $50 billion). The sales of Peppers began in 2014. This robot is currently being used at Japanese medical facilities and as a receptionist in several offices in the UK and North America. The price of a Pepper robot is about $1,500 per robot, but Pepper is only sold on a payment agreement that involves a network data plan and equipment insurance. This costs $360 per month and is paid over 36 months, bringing the total cost of ownership to over $14,000 [40].

Paro has the appearance of a seal and emits its cries. It is about the size of a baby and weighs 2.5 kg. When switched on, he comes to life, opening and closing his eyes, raising his head, and wriggling his tail. It can recognize approximately 50 words and has sensors that allow it to recognize differences between day and night. Paro was designed by T. Shibata of the Intelligent System Research Institute (Japan) in 1993. Shibata's Intelligent System Co. has invested $15 million to develop this robot, and its hand-built versions have been sold by the company since 2004. In Japan, it sells for about 2,700 euros. The Qoobo robot looks like a cat, but it has no head, no legs, no claws, or mustaches but simply a body and a tail that moves. The robot is covered in fur as soft as a real cat. Qoobo is for people who suffer from loneliness in their daily lives and cannot keep pets due to allergies, living environment, physical problems, etc. Over 20,000 Qoobos have been sold both in Japan and overseas. It was created by Yukai Engineering (Japan) which specializes in the development of lifestyle robots including Qoobo. The price of Qoobo is about $100.

In many countries, a number of small companies have created social robots that perform various functions of caring for elderly patients in hospitals and nursing homes and simply helping elderly people in everyday life. For example, Diligent Robotics, founded in 2014 by Andrea Thomaz and Vivian Chu, developed an AI-powered robot known as Moxi. This autonomous robot is able to perform everyday tasks and assist nurses. Today the company is a leader in the segment of auxiliary robots [41]. ST Engineering, a Singapore-based engineering firm, has a Pittsburgh-based Aethon division that manufactures autonomous TUG robots to deliver materials and sanitize hospitals, providing healthcare workers more time to care for patients [42].

It can be expected that with the growth in the number of developments, manufacturers, and the advent of serial samples, the prices of robotic nurses will fall. Right now, in Japan, human-like robots are already being utilized as supplemental healthcare workers in elderly homes across the country. Larger robots can be used to carry out tasks like moving patients, and smaller interactive robots are being used to combat the loneliness and inactivity of the elderly population [43].

5. DISCUSSION

This study is based on data sources showing the use of robotic surgery, robotic rehabilitation, and social robots to treat and care for older patients. We found that the use of robotic surgery and robotic rehabilitation has steadily increased in the 21st century in all procedures, especially in areas such as urology and gynecology, which are common to the elderly. The insufficiency of clinical data makes it difficult to evaluate the implication of this rapid intrusion of robotics into medical practice. It also limits the regulators to monitor or, more broadly, assess the public health implications of rapid changes in medicine.

This paper shows that currently most of the robotic operations are carried out in the USA, Germany, and Japan, which have developed robotic industry and a high standard of living. According to the financial statements of medical robotics manufacturers, sales of robotic surgical systems have been quickly growing over the past decade, slowing down slightly due to COVID-19 only in 2020. Further expansion of the use of robotic systems in surgical operations and rehabilitation is constrained by the relatively high cost of these systems. We hope to draw the attention of researchers from technical universities and high-tech companies to the problem of population aging and its partial solution with the help of medical robotics.

6. CONCLUSION

The problem of population aging affects all countries and causes an increase in the burden on medical facilities and the need to increase medical staff. Developed countries partially solve the problem of insufficient medical staff by attracting specialists and nurses from developing countries. An alternative to the migration of specialists is the robotization of the medical industry using innovations in science and technology.

Medical robotic systems allow for high-precision and safe minimally invasive surgical operations that the elderly need. They help to restore limb functions after illnesses or surgeries and also help medical staff in servicing medical institutions. Further development of medical robotics and increasing competition among manufacturers will lead to a decrease in the price of medical robots and services, facilitate the work of doctors and make the medical processes even safer and more efficient.

Medical robotics companies are concentrated mainly in the USA, Japan, and European countries, but in recent years this direction in robotics has been dynamically developing in South Korea, China, and Singapore. Accordingly, these countries have concentrated the bulk of patents and publications devoted to the creation and application of medical robots, including for solving problems associated with population aging.

The leading technical universities of the world are multidisciplinary and have high positions in the science of life and medicine. Many medical robotic systems are created in scientific laboratories of technical universities and then introduced into industrial production.

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