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Exploring Telemedicine: a comprehensive overview of telemedicine, telemonitoring, and technologies for remote health and hypertension monitoring

Author: Alexandra Navarro Masuet
Supervisors: Carlos Oscar Sorzano

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ABSTRACT

According to the INCLASNS (Key Indicators of the National Health System) offered by the Ministry of Health of the Spanish government, the evaluation of primary care family doctors by users in Spain's public healthcare system in 2022 received a positive rating of 80.49% [1]. Similarly, specialist doctors received a positive rating in 82.73% of cases [1]. However, the system encounters substantial challenges, being the mounting life expectancy and the resulting surge in demand for healthcare services the most notable one. To address this escalating service demand, many hospitals are actively acquiring new technologies to adapt the public healthcare system's capabilities. This strategic approach aims to enhance their capacity to cater to patients effectively.

The main goal of the project is to showcase the potential and advantages that digital technologies can offer an innovative approach to healthcare. These cutting-edge technologies encompass telemedicine systems, portable medical devices, and digital communication platforms. By implementing these advancements, healthcare providers can remotely monitor patients, making it easier to track their health status and minimizing the need for unnecessary travel. These tools play a vital role in the successful establishment of new ways of delivering health services, such as teleconsulting and telemonitoring, which can converge into new approaches like home hospitalization units. By enabling personalized, efficient, and high-quality patient care, these advancements ultimately contribute to the continuous improvement of the Spanish healthcare system.

RESUMEN

De acuerdo con el INCLASNS (Indicadores Clave del Sistema Nacional de Salud), ofrecido por el ministerio de sanidad del gobierno de España, la valoración de la atención del médico de familia (atención primaria) por parte de los usuarios en la sanidad pública en España en el año 2022 mereció una calificación de positiva en el 80,49 [1]. Por su parte los médicos especialistas recibieron una valoración positiva en el 82,73% de los casos [1]. Sin embargo, dicho sistema se enfrenta a importantes retos, siendo el más relevante el incremento de la esperanza de vida de la población y el consecuente incremento de la demanda de servicios sanitarios. Con el fin de adaptar los medios del sistema de salud pública a esta situación, muchos centros están incorporando activamente el uso de nuevas tecnologías. El uso de la teleconsulta o la telemonitorización está permitiendo el desarrollo de nuevas formas de atención, como las unidades de hospitalización domiciliaria. Con esta estrategia esperan poder incrementar su capacidad de atención a pacientes.

El objetivo del proyecto reside en poner de manifiesto el potencial y los beneficios que las nuevas tecnologías digitales pueden suponer para el desarrollo pleno de esta nueva modalidad de atención. Estas ciencias aplicadas incluyen sistemas de telemedicina, dispositivos médicos portátiles y plataformas de comunicación digital. Su implementación permite una monitorización remota de los pacientes, facilitando el seguimiento de su estado de salud y reduciendo la necesidad de desplazamientos innecesarios. Todas estas herramientas son fundamentales para el desarrollo exitoso de estas nuevas formas de atención sanitario como las unidades de hospitalización domiciliaria, ya que permiten una atención personalizada, eficiente y de calidad a los pacientes, contribuyendo así a la mejora continua del sistema sanitario español.

INDEX

FIGURE INDEX

TABLE INDEX

1 INTRODUCTION

1.1 Context and aim of the project

The healthcare system in Spain is currently confronting a major challenge that demands careful attention and effective strategies to ensure high-quality and sustainable medical care. The increasing life expectancy of the population is leading to a gradual aging of society. According to the World Health Organization (WHO), life expectancy is expected to continue rising worldwide, resulting in most individuals reaching the age of sixty and beyond [2]. In Spain, the National Institute of Statistics (INE) reports that the proportion of individuals aged 65 and above, currently at 20.1% of the total population, is projected to peak at 30.4% by approximately 2050, equivalent to around 18.2 million people [3].

This increase in life expectancy brings forth important implications for the healthcare system, resulting in its overload. [4]. Currently, there is a surge in demand for healthcare services as the elderly population tends to require more medical attention and specialized care. Based on a series of collected data, it is believed that healthcare spending attributed to individuals aged 65 and older is three times higher than that of the population segment below that age [5]. This includes treatments for chronic diseases, long-term care, palliative care, and other health needs associated with aging. Demographic forecasts indicate that this increase in population longevity will also lead to a rise in chronic conditions, which already account for over 80% of primary care consultations and are a frequent reason for specialist visits [4]. Consequently, it can be concluded that the current healthcare system faces the challenge of meeting the growing demand for medical care and ensuring the capacity to provide health services, ensuring the evolution and sustainability of the system [6].

At the same time, it should be noted that we are witnessing a growing number of developing technologies that propose new methodologies for delivering medical services and are being considered as potential solutions to the previously mentioned challenges.

The purpose of this project is to investigate these technological advancements, revealing how they can develop in new approaches to health care services, such us teleconsulting, telemonitoring and the concept of home hospitalization. The study aims to highlight its potential value as a tool that can contribute to addressing current challenges and strengthening the evolution and sustainability of the healthcare system for the benefit of patients and healthcare professionals.

1.2 Problem definition

As previously mentioned, the current healthcare landscape in our country is facing significant pressures to undergo necessary changes that align with the evolving needs of our aging population. The present challenge is to create a healthcare system capable of effectively meeting the increasing demand for services while managing the associated rise in healthcare expenditure. Three distinct perspectives have emerged in understanding this challenge: rise in the aging population, growing demand for healthcare services and chronic disease progression.

In the following sections we will explore each of these perspectives, providing a detailed analysis and description of their implications.

1.2.1 Rise in the ageing population

In numerous countries, particularly those that are developed, the life expectancy of the population has consistently risen in recent decades. This remarkable progress can be attributed to significant advancements in medicine, along with advancements in public health, personal hygiene, and environmental factors [7]. It is predicted that, by the year 2045, the population of vulnerable senior citizens in society will surpass the count of children and young adults [8].

According to data published by the National Institute of Statistics, Spain experienced a population growth, from 2010 to 2022, at an annual compound growth rate of 0.2%. The population increased by 1.1 million people, rising from 46.5 million to 47.6 million. In terms of age groups, individuals aged 60 years or older represented 22.4% of the total population in 2010. Since then, this segment has continued to grow at an annual compound rate of 1.7%, reaching approximately 27% of the Spanish population in 2022, which is equivalent to around 12.8 million people. This implies that the population group of adults aged 60 years and above grows by approximately 200,000 individuals each year [9]. The graph represented in Figure 1 visually illustrates the demographic growth, both in the overall population and in the segment of individuals aged 60 years and older. Based on the graph represented in Figure 1, the conclusion that the overall demographic growth has shown fluctuations in recent years can be drawn. It experienced a decrease from 2013 to 2016 but has been on the rise since then. In contrast, the population segment of individuals aged over 60 years old has exhibited a consistent and exponential growth for more than a decade.

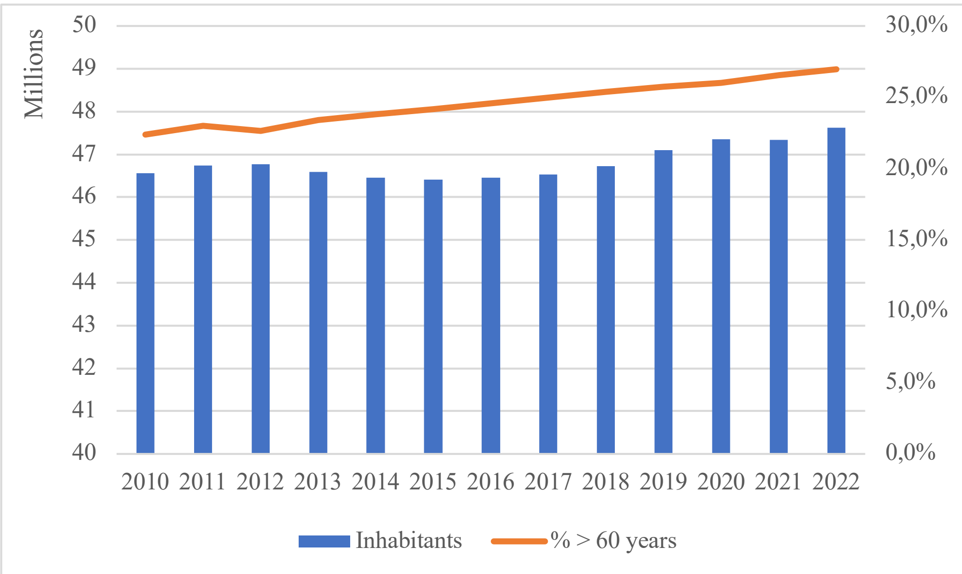

Figure 1 Increase in total population and age group 60 or older from 2010 to 2022.

1.2.2 Growing demand for healthcare services

After a period of budget cuts in various sectors, due to the economic crisis that began in 2008, public healthcare spending in Spain started a significant upward trend in 2014. Both the total expenditure and per capita figures witnessed a substantial increase [10]. This growth initially stemmed from economic recovery and the gradual overcoming of the crisis, surpassing the peak spending recorded in 2009. In 2018, healthcare spending reached €71,091 million, exceeding the previous record of €70,724 million [10]. However, it was from 2020 onwards that the healthcare expenditure experienced even greater growth, driven by the extraordinary needs arising from the COVID-19 pandemic [10]. In 2021, total healthcare spending amounted to €87,941 million, with per capita expenditure reaching €1,858 [10]. In Figure 2, a significant surge in healthcare spending in 2020 is shown, as well as the ongoing upward trend in per capita expenditure over the past decade.

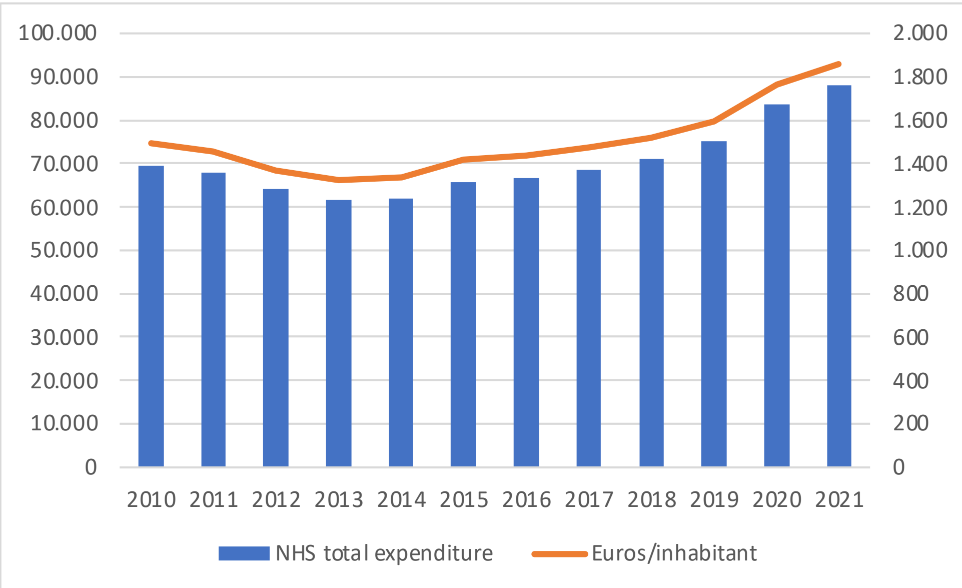

Figure 2 Total healthcare expenditure for the entire population and per capita from 2010 to 2022.

Additionally, the study "*Distribution of Public Healthcare Expenditure by Age and Gender in Spain: Analysis of the Decade 1998-2008*" examines the public healthcare spending according to typology, providing an indicator of the expenditure on individuals aged 65 and older during the period from 1998 to 2008 [5]. According to this research, in 2008, the annual total expenditure on individuals aged 65 and older is nearly three times higher than the expenditure on the younger population segment. This difference increases significantly when it comes to specialized care involving hospital admissions, where the expenses for caring for individuals aged 65 and older are 4.51 times higher than those for the population under that age [5]. Following, the data collected from the previously mentioned study can be seen in Table 1.

Table 1 Annual Healthcare expenditure per person by level of healthcare for individuals under and over 65 years of age.

	0-64	>65	Ratio
Primary care	135 €	271 €	2,00
Outpatient Specialized care	186 €	325 €	1,75
Inpatient Specialized care	191 €	860 €	4,51
Pharmacy	139 €	459 €	3,30
Total expenditure per person	741€	2.196 €	2,96

Table 1 displays the individual healthcare expenses for individuals below and above the age of 65. As we can see in the ratio column, individuals aged 65 or older consume almost three times more healthcare resources than the rest of the population. Having a closer look, it can be observed that there is a turning point after a certain age. At that point, primary care expenses for individuals aged 65 or older double, specialized outpatient care expenses increase significantly, hospitalization expenses multiply by four, and pharmaceutical consumption triples. These figures confirm that the aging population poses a challenge to the healthcare system. Not only is the healthcare expenditure for this population segment notably higher than that of other individuals, but it is also a potentially growing segment, which could likely destabilize the system.

1.2.3 Chronic disease progression

With the growing prevalence of a larger population and aging, chronic diseases also play a role in the ongoing rise of healthcare costs. As a result, it becomes necessary for the system to undergo a vital transformation, shifting from the traditional hospital-centered model to an individual-centered approach [11]. According to the World Health

Organization (WHO), non-communicable diseases (NCDs), also known as chronic diseases, are typically long-lasting and result from a combination of genetic, physiological, environmental, and behavioral factors [12].

The graph represented in Figure 3 illustrates the top ten most common chronic diseases among the Spanish population. As can be seen, the most prevalent condition is hypertension, affecting approximately 19.05% of the total population, which accounts for around 9 million individuals [13].

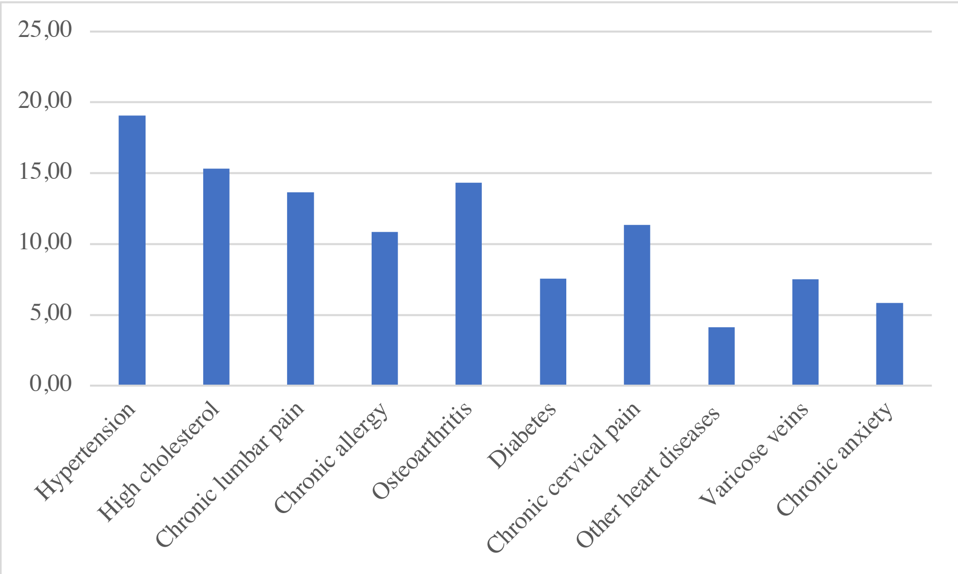

Figure 3 Most prevalent chronic diseases among the population.

In our country, six out of ten adults suffer from some form of chronic disease [14]. The prevalence of, at least, suffering from one exceeds 77% in the age group of 65 and older [15]. Additionally, in Spain, around 80% of healthcare expenditure is allocated to managing chronic diseases [15]. Therefore, it becomes evident that there is a clear need to transform the approach in how the affected population is treated.

The present project includes a dedicated section on hypertension that offers a more comprehensive understanding of it, along with an overview of the technologies used for its telemonitoring. The objective is to explore the potential of current technology in effectively addressing the described issue.

2 OBJECTIVES OF THE PROJECT

The aim of this study is to offer a comprehensive, clear, and organized overview of the key aspects of telemedicine and, more specifically, telemonitoring, as well as their application in the diagnosis and remote evaluation of arterial hypertension. The objective is to provide insights into the status of these technologies and their application in the field of hypertension management. The sequential approach followed in the process of obtaining the information is presented in Figure 4.

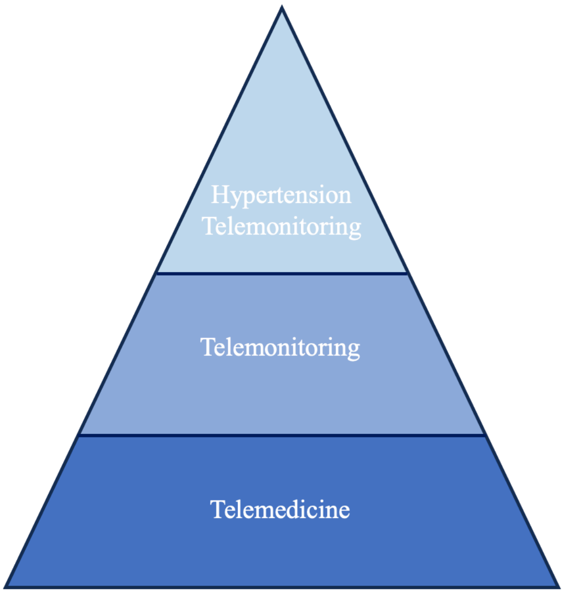

Figure 4 Sequential approach of the information.

To accomplish the mentioned aim, the following steps have been considered:

- Conducting a thorough search for scientific and non-scientific information to gain insights into telemedicine, telemonitoring, and hypertension remote evaluation and diagnosis.
- Establishing the inclusion criteria to select relevant and reliable information that meets predefined standards.
- Presenting the results based on the information that met the requirements mentioned.

3 MATERIALS AND METHODS

The present study focuses in providing a comprehensive overview of telemedicine, along with a more detailed examination of telemonitoring, specifically focusing on the utilization of telemonitoring tools for the management of arterial hypertension. To accomplish this objective, the following two approaches have been taken in account: information search and analysis-based methodology and an interview with a healthcare professional.

3.1 Approach 1: Information search and analysis-based methodology

The present study relied on a combination of scientific and non-scientific information that has been registered in an Excel document containing relevant aspects such as title, authors, and a link to the source among others. Such document can be accessed through the following link: https://github.com/alenavaarro/Appendixes.git

The methodology and search criteria for obtaining and filtering this information varied depending on whether it belonged to the scientific or non-scientific category. The following sections outline the specific processes undertaken for each case.

Additionally, it is important to note that two distinct investigations were conducted. The first focused on acquiring information about telemedicine and telemonitoring, following the requirements exposed in the subsequent sections. Afterwards, a similar strategy was employed to obtain relevant data on hypertension telemonitoring. This distinction is crucial as it influenced some of the requirements and approach used in the search process. To provide a comprehensive explanation, a clear distinction has been made and referred to as the "telemedicine and telemonitoring investigation (TTI)" and the "hypertension telemonitoring investigation (HTI)."

3.1.1 Scientific information search

Information was analyzed and studied following the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) systematic review methodology [16].

Article search strategy

For the obtention of scientific information for both investigations, TTI and HTI, Google Scholar and PubMed databases were used. In the case of the TTI, databases were search employing key words "Remote patient monitoring", "Telemedicine", "Patient monitoring systems" and "Remote health monitoring". Additionally, a search in Google Scholar database was conducted using the key word "Telemedicina" to gain more insights of the filed in Hispanic countries. In the case of HTI, the key terms employed were "Arterial Hypertension monitoring" and "Blood pressure monitoring devices". Additionally, three separate searches were conducted employing a temporal filter with each of the previously mentioned key words. Initially, the filter was used to narrow down articles published from 2020 onwards, followed by articles published from 2018 onwards, and ultimately articles published from 2010 onwards.

Article inclusion and exclusion criteria

The inclusion and exclusion criteria differed depending on the database.

Google Scholar

In addition to considering the year of publication, the filtering process also took in account the number of citations for each article. The specifications defined for the TTI when searching in both databases the English key words were the following:

- Articles should have 150 or more cites if published from year 2020 onwards
- Articles should have 300 or more cites if published from year 2018 onwards
- Articles should have 500 or more cites if published from year 2010 onwards

However, due to the less amount of available information, the requirements followed when searching in Google Scholar with the key word "Telemedicina" were the followings:

- Articles should have 15 or more cites if published from year 2020 onwards
- Articles should have 30 or more cites if published from year 2018 onwards

- Articles should have 50 or more cites if published from year 2010 onwards

In the case of the HTI, the requirements specificized to include or exclude articles were the followings:

- Articles should have 100 or more cites if published from year 2020 onwards
- Articles should have 150 or more cites if published from year 2018 onwards
- Articles should have 300 or more cites if published from year 2010 onwards

PubMed

In this case, the first five articles displayed using the additional filter "Best match" where selected in each of the searches based on key word and temporal filter combination.

Article validation criteria

The number of articles registered from Google Scholar considering both English and Spanish key words together with the ones collected from PubMed database regarding the TTI was 129 articles. In the case of the HTI, the searching process registered a total of 53 articles. The subsequent step involved validating the registered articles that met the predetermined criteria. For both TTI and HTI, four exclusion specifications were considered:

- Duplicate articles
- Relevance based on the abstract
- Relevance based on the content of the study
- Unavailable articles

3.1.2 Non-scientific information search

To supplement the information obtained in both investigations and ensure the availability of the maximum amount of data possible for this project, a search for non-scientific information was also conducted. In addition to articles, reports, and blog publications were also taken in account. The tool employed was Google web browser and the following criteria were considered for including information:

- Information had to be published from 2018 onwards
- Information had to originate from reliable sources, such as governmental or medical institution sites, scientific or medical blogs, reputable sites or magazines, and well-known informational sources like newspapers

The results obtained following the non-scientific searching approach described were 172 elements for the TTI and 28 elements for the HTI.

3.1.3 Information search results

After conducting both scientific and non-scientific searches, the results from the research dedicated to telemedicine and telemonitoring, or TTI, are presented in Figure 5. Meanwhile, the findings from the study focused on telemonitoring for hypertension, or HTI, are shown in Figure 6.

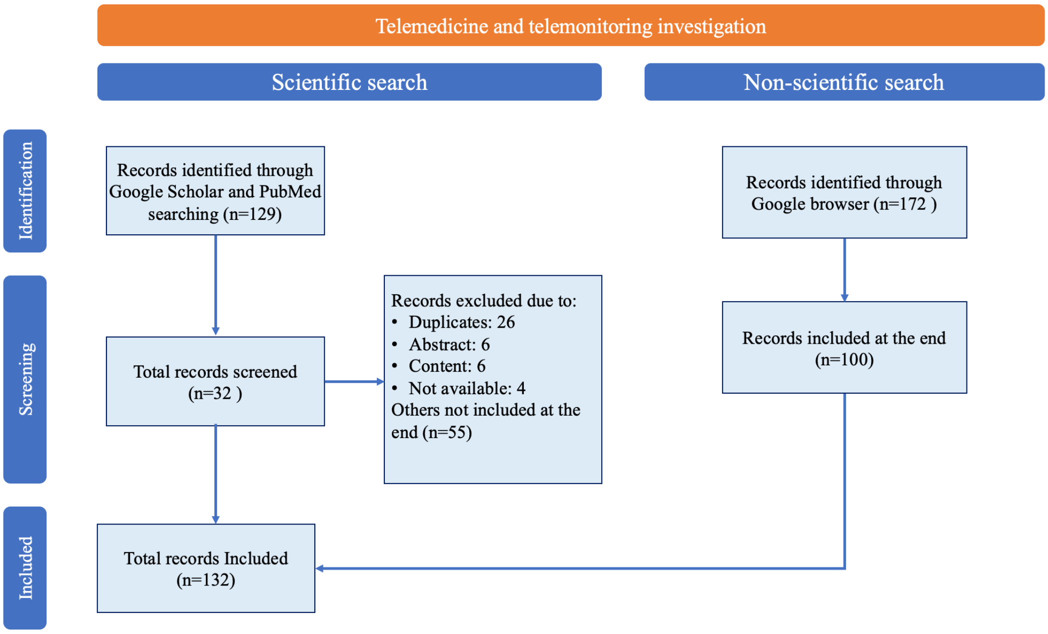

Figure 6 Searching and screening process results of the telemedicine and telemonitoring investigation.

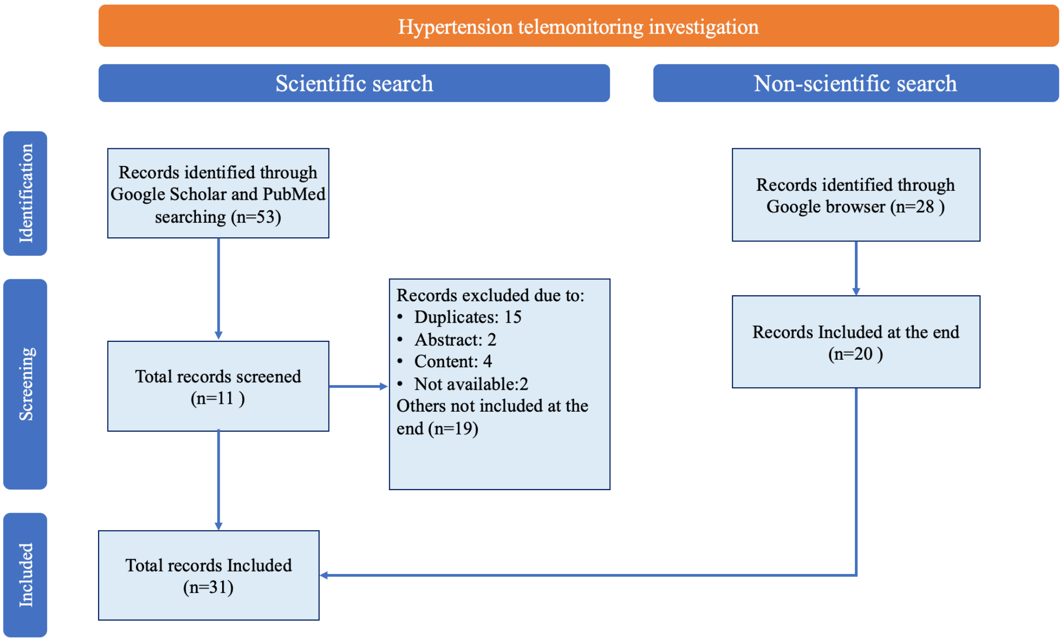

Figure 5 Searching and screening process results of the hypertension telemonitoring investigation.

3.2 Approach 2: Interview with healthcare professional

To complement the information obtained through the search, filtering, and analysis conducted in the previous section, an interview was carried out with a primary care physician. The interview explored various aspects, including the variability of blood pressure throughout the day, the complexities associated with diagnosing arterial hypertension, and the primary challenges currently encountered in the diagnostic process. Additionally, the interview highlighted the significant problem of a considerable proportion of the population being underdiagnosed for this condition.

4 Results

This section presents a comprehensive overview of telemedicine, including its definition, history, and background. It examines the factors contributing to its expansion, as well as its applications, advantages, and disadvantages. The subsequent part provides a more detailed exploration of telemonitoring. Apart from including its definition, historical background, and evolution, a classification of the technologies applied in telemonitoring is presented, along with descriptions of each technology. The following section shifts the focus to hypertension, covering its definition, types, and the technologies used for its remote evaluation. Finally, an interview with an expert physician in the field offers valuable insights into the current challenges encountered in the diagnosis and telemonitoring of this chronic condition.

4.1 Overview of telemedicine

4.1.1 What is telemedicine?

To grasp the concept of telemedicine, it is crucial to gain an understanding of telehealth first. Telehealth entails utilizing technology-based virtual platforms to provide a wide range of health information, prevention, monitoring, and medical care services [17]. Telemedicine, which is considered telehealth's largest segment and constates the fastest-growing sector within the field of healthcare [17], is defined by the WHO as: *"The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities" [18].*

4.1.2 Historical background, origin and development

Telemedicine has a long history that dates back centuries. In the 14th century, the heliograph was invented as a means of communication during the bubonic plague [19]. Later, in 1829, the telegraph revolutionized long-distance communication [19]. The telephone and radio broadcasting followed in the late 19th century [20]. In 1890, the

Estetophone combined the stethoscope and telephone for distant auscultation [21] [22]. The concept of telemedicine emerged in 1924 with a futuristic illustration in Radio News magazine [21]. It gained popularity in the 1960s with advancements in military and space technology [18]. The internet's emergence in the 1980s and the digital era of the 1990s further propelled telemedicine, leading to comprehensive advancements in patient education, image transmission, real-time consultations, and vital sign monitoring [23]. However, internet at that time presented some fundamental issues that made it difficult for population to access [24]. It wasn´t until the integration of broadband, shortly after internet, that this service became much more accessible since it came along with much faster connection speeds, making it a lot easier to browse the internet and download & send files [24]. Ongoing technological advancements have made telemedicine widely accessible, with the development of smart sensors, wearable gadgets, and internet-connected devices [25] [26].

4.1.3 Telemedicine expansion

In this study, the expansion of telemedicine has been attributed to a key event which is the COVID-19 pandemic and the fact that the access to technology among the population has increased.

COVID-19 pandemic

Over the years, the expansion of teleconsultations, including telemedicine, has shown significant growth (see Figure 7). The onset of the COVID-19 pandemic in 2020 further accelerated the adoption and utilization of teleconsultations, and this trend has continued even after the event. The following presented data has been obtained from the "Key indicators of the National Healthcare System" presented by the Spanish Ministry of Health [10].

In 2017 and 2018, while data specifically regarding teleconsultations is unavailable, the number of consultations at primary attention medical centers and home visits remained relatively stable. However, the shift towards telemedicine was about to become more pronounced.

By 2019, the number of teleconsultations accounted for approximately 5.4% of the total consultations, with 18.1 million recorded. This represented a substantial increase, signaling a growing acceptance of telemedicine as an alternative and convenient means of seeking medical advice and treatment.

The impact of the COVID-19 pandemic became evident in 2020. The number of consultations at medical centers experienced a significant decrease of approximately 32.2% compared to the previous year, while consultations at home remained relatively steady. In contrast, teleconsultations surged to approximately 34.6% of the total consultations, with a remarkable 126.9 million recorded. This sharp increase underscored the necessity and effectiveness of remote healthcare delivery during the pandemic.

Even as the situation improved in 2021, teleconsultations continued to thrive. While the number of consultations at medical centers experienced a modest recovery, teleconsultations accounted for approximately 37.9% of the total consultations, with a new high of 167 million recorded. This data highlights the enduring popularity and widespread adoption of telemedicine, with individuals increasingly appreciating the convenience, accessibility, and reduced infection risk associated with remote consultations.

This data demonstrates the growing acceptance and adoption of teleconsultations, which has been further propelled by the COVID-19 pandemic. It emphasizes how telemedicine has become an integral part of healthcare delivery, providing an essential and effective means for individuals to access medical care remotely and safely.

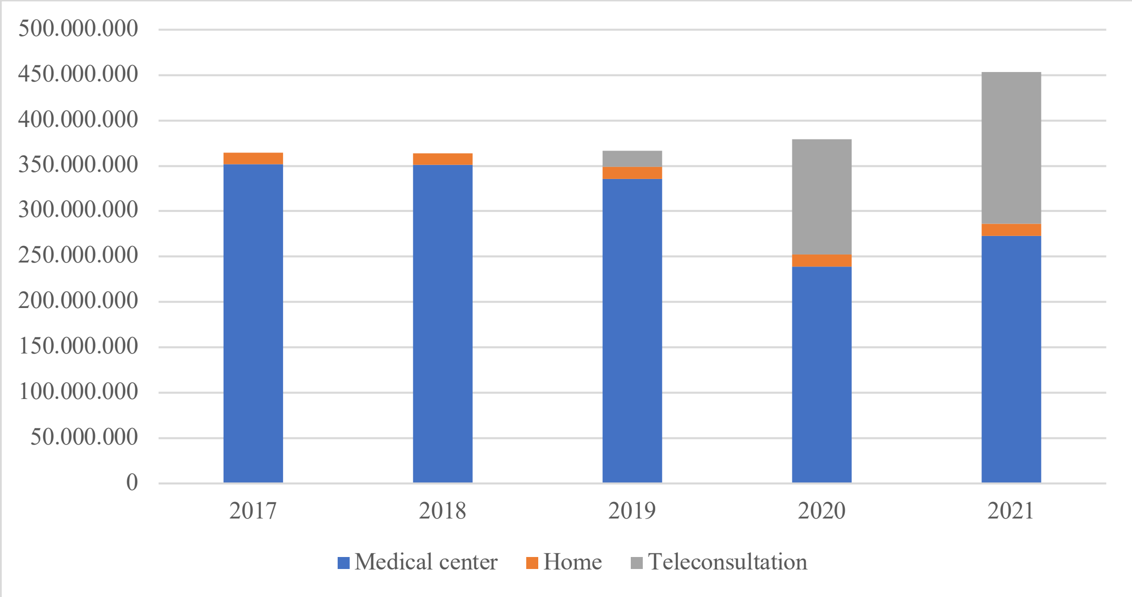

Figure 7 Medical consultations in primary attention services from 2017 to 2022.

Increased access to technology

According to the survey conducted by the National Institute of Statistics (INE) in November 2022 [27], which focused on the equipment and usage of information and communication technologies (ICT) in Spanish households (known as the ICT-H survey), the results reveal a significant increase in technology adoption and connectivity (see Figure 8). The findings highlight that 96.1% of Spanish households now have internet access, representing a significant increase from 82.7% in 2017. Additionally, 82.9% of households have some form of computer, with desktops or laptops present in 77.9% of homes and tablets in 55.4% of homes. Nearly all households (99.9%) have at least one type of telephone, and 62.1% have both landline and mobile phones. The survey also found that, when examining the frequency of internet usage among individuals between the ages of 16 and 72, the majority connect to the internet on a weekly (92.9%), daily (87.1%), or multiple times a day (84.2%) basis, indicating a high level of digital engagement. These findings highlight the widespread integration of technology and the increasing reliance on digital devices in Spanish households.

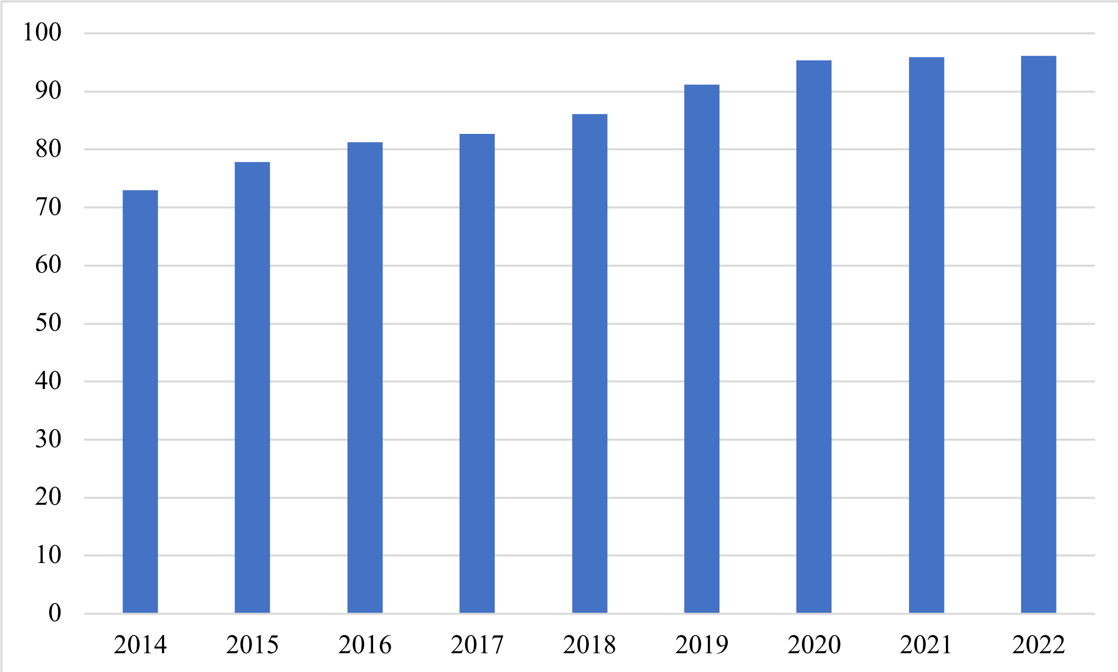

Figure 8 Technological equipment and ICT utilization in Spanish households in 2022.

The rise of teleconsultations during the COVID-19 pandemic demonstrates its adaptability and the changing behavior of patients. The high percentage of households with internet access and reliance on digital devices support the integration of telemedicine into healthcare systems. Telemedicine offers convenience, accessibility, and improved patient outcomes. It is becoming an essential tool for healthcare providers, enabling efficient resource utilization and collaboration. Telemedicine's continued growth is expected, providing greater access to care, and transforming the healthcare industry.

4.1.4 Types and applications of telemedicine

In the process of categorizing the telemedicine applications, a challenge arises in the form of lack of agreement on taxonomy criteria. After having reviewed numerous articles, scientific and medical blogs, and reports, it has been noted that there is currently no universally accepted classification for the types and applications of telemedicine. Different articles mention three ways in which this modality can be offered: synchronous telemedicine, asynchronous telemedicine, and telemonitoring [28]. Others argue for a division into four main categories: teleconsultation, telediagnosis, telemonitoring, and tele-surgery [29]. Some even include teleradiology as an additional application [30], although it is sometimes considered part of telediagnosis. As can be seen, there is no clear consensus on how to categorize this new approach to healthcare across its various applications. In this study, a clear and simplified framework for organizing the different branches within the field of telemedicine at a general scale has been provided. (see Figure 9).

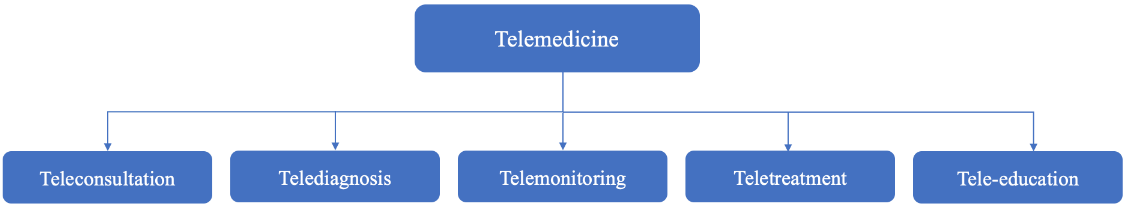

Figure 9 Organizational overview of telemedicine applications at a general scale

A description of each of the application featured in Figure 9 is provided, offering a comprehensive understanding of the specific roles and functionalities attributed to these telemedicine applications:

- Teleconsulting: it refers to the contact between patients and physicians through a platform, eliminating the need for intermediaries [31]. The goal is to provide patients with convenient access to the knowledge and advice of a remote expert [31]. Currently, teleconsultation accounts for approximately 35% of the total usage of telemedicine networks [32]. Teleconsultation is typically conducted through video connections or online platforms like Facetime, internet, Skype, and others [33]. It takes place in a designated room where the healthcare professional actively engages in listening to the patient's concerns [34]. Ensuring a confidential environment for the patient is crucial to maintain the privacy of the shared information [34].

- Telediagnosis: it involves the remote transmission of medical records and examination findings to a specialist, regardless of their geographical location. The use of telediagnosis platforms must ensure that the quality and privacy of images and videos is preserved, even after compression for transmission [35]. These platforms utilize information and communication technologies (ICT) to facilitate the delivery of this diagnostic service [36]. There are two distinct approaches for delivering telediagnosis:

- Asynchronous: this type of interaction, commonly referred to as store-and-forward [37], involves recording medical information at 1 site and then transmitting the recorded information to another site or sites for evaluation by a medical specialist later [38]. It enables the transfer of pre-recorded information without the simultaneous presence of those involved [39]. This can involve scenarios where a patient or referring healthcare professional sends a detailed email describing a medical case to an expert, who then analyzes the information and provides their expert opinion on the diagnosis and recommended treatment options [18]. Healthcare professionals and patients may engage by storing and forwarding clinical data elements, such as medical reports, images, and video recordings, to be interpreted later [40], usually through patient portal messages or e-consults [41]. Asynchronous telediagnosis is widely used in various medical specialties such as dermatology, neurology, ophthalmology, cardiology, and otolaryngology [39].

- Synchronous: this second method of delivering telemedicine, also referred to as real-time [42], interactive [43], or live telemedicine [38], involves an immediate interaction between the participants involved at two or more sites [44]. It requires simultaneous presence to enable instant information exchange [18]. In this delivery methodology, healthcare professionals and patients predominantly interact via fully interactive video technology [40] [45] or via telephone means [46]. Synchronous telemedicine is particularly useful for quick decision-making, especially in emergency situations [39]. It provides the opportunity to obtain an immediate second opinion, which is crucial for critically ill patients or those with life-threatening injuries [39].

- Telemonitoring: also known as remote monitoring [31], is an innovative strategy that digitally transmits disease-related and physiological data from patients' homes to healthcare centers providing clinical feedback [31]. It enables early detection of disease decompensation, reduces mortality and hospitalizations [47], and empowers patients in their healthcare [47]. Telemonitoring systems reduce physical contact, waiting times, and overall healthcare costs for patients while alleviating the workload on medical staff [8]. The technology employed in telemonitoring ranges from sensors attached to the body to ambient sensors in the environment, with recent advancements enabling contactless monitoring within proximity to the patient [48]. Regardless of the technology, the purpose is to monitor vital signs like heart rate (HR), blood pressure (BP), and glucose levels [48]. Information and communication advancements have greatly contributed to the development of modern healthcare systems, including telemedicine solutions [8].

- Teletreatment: involves providing treatment practices remotely, making use of different techniques and technologies depending on the specific type of service. One of the most common types of teletreatment approaches is telesurgery. Telesurgery, or tele-intervention, involves a surgeon performing operations on a patient located at a distance [49]. Its primary goal is to address the current unmet needs in healthcare by making surgery accessible, affordable, and of high quality [47]. There are two methods of conducting tele-surgery: telementoring and telepresential approaches [32].

  - Telementoring surgery: the specialist provides remote assistance to a surgeon in performing surgical procedures [32].

  - Telepresential surgery: the specialist itself, utilizing advanced technology, performs the intervention remotely [32].

Increasingly, remote interventions make use of robotic systems, such as the Da Vinci Surgical Robotic System [50]. Its latest version provides enhanced 3D vision and stability since it eliminates physiological tremor, benefiting multiple surgical specialties such as urology, general surgery, oncological gynecology, oral and maxillofacial surgery, pediatric surgery, thoracic surgery, and cardiac surgery [37]. It is worth noting that this application of telemedicine also serves as an educational tool, allowing students and professionals in the field to remotely observe surgical procedures in real-time [51].

- Tele-education: it is defined as continuous education measures customized for the patients and professionals needs [46]. Able to remotely deliver education both to health care workers and to patients [33], it provides valuable opportunities for learning and growth by facilitating the distribution of general information and offering remote training options [18]. To fully exploit the potential of telemedicine and promote its integration into the existing healthcare system, it is crucial to provide training and education for both medical professionals and users [52].

  - To users: it supports the patient's healthcare education in preventive medicine and public health [53], by providing health information to the general population. This includes promoting healthy lifestyles (nutrition, lifestyle, etc.) and raising awareness about specific diseases [54]. Moreover, it allows users to familiarize with new technologies and learn how to utilize them. In combination, it encourages the adoption of this innovative tool by informing users of their available options and gradually helping them embrace new approaches to receiving medical assistance [55].

  - To professionals: it facilitates dialogue between clinicians in industrialized and developing countries [18]. Also, it permits healthcare professionals in different geographical locations to engage in discussions, share insights, and analyze cases, with the aim of drawing conclusions from these meetings and expanding their knowledge [28]. Additionally, it allows access to diverse forms of medical training [43]. For instance, both students and healthcare professionals can observe real-time interventions and receive detailed explanations simultaneously [30].

The most common approach to delivering tele-education is through medical video conferences. In these conferences, instructors can share knowledge with individuals regardless of their geographic location. This guarantees that participants receive content from highly skilled experts, ensuring a high-quality teaching and learning processes [56].

The presented telemedicine applications contribute to enhance the efficiency of the healthcare system. This healthcare system is organized into different levels based on the type of care provided. According to the Annual Report of the Spanish Ministry of Health [57] for the year 2020-2021, the classification is as follows (see Figure 10).

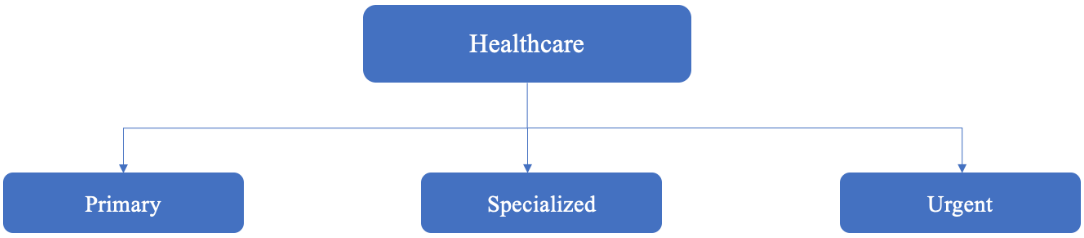

Figure 10 Levels of healthcare attention.

Primary care

Primary care is the foundational and primary level of healthcare [58] that ensures comprehensive and continuous care throughout a patient's life. It acts as a coordinator, regulating the flow of healthcare services. It encompasses various activities, including health promotion, health education, disease prevention, healthcare provision, health maintenance and recovery, as well as physical rehabilitation and social work [59]. All these services are characterized by their high accessibility and sufficient technical capacity to fully address commonly encountered healthcare issues [57].

Specialized care

Specialized care forms the second level of healthcare in the structure of healthcare systems [57]. This level provides access to advanced diagnostic and therapeutic resources, which are typically initiated through referrals from primary care physicians [57]. The main goal is to ensure uninterrupted and comprehensive care for patients when primary care reaches its limits, offering the required care and treatment until the patient can be transitioned back to that level of care [59]. Two different types withing specialized can be distinguished:

- Outpatient: in first type of specialized, are provided with the necessary services and treatments in order to be retransition to assistance care level without the need of being hospitalized [60].

- Inpatient: in this second branch of specialized care, it encompasses medical, surgical, obstetric, and pediatric assistance, along with the provision of diagnostic treatments or procedures for patients who require continuous care that requires hospitalization [61]. Patients can access specialized care in a hospital setting either through a referral from a specialist physician or via hospital emergency services. This is applicable when the patient needs specialized and ongoing care that cannot be provided on an outpatient or home basis [61].

Urgent care

Finally, emergency, or urgent care, also known as the third care level [58], is provided to patients when their clinical condition requires immediate medical attention. It is available around the clock, both in healthcare facilities and outside of them, including at the patient's home and through on-site assistance. This comprehensive care requires the active participation of medical and nursing professionals, along with collaboration among various healthcare providers [62].

Telemedicine has proven to be particularly beneficial for both primary and specialized care, making them more accessible. Referring to the data represented in Figure 7, it can be observed that in the year 2018, when remote consultations were not yet fully implemented and widely available, the total number of consultations was 364,098,667. However, with the onset of the COVID-19 pandemic, which necessitated the provision of medical services at a distance, such as virtual consultations, the number of consultations in that year rose to 453,023,901. This indicates that the adoption of telemedicine boosted the number of provided consultations by nearly 25%. These findings highlight a significant increase in the utilization of telemedicine and its positive impact on enhancing accessibility and effectiveness in delivering healthcare services.

4.1.5 Benefits and drawbacks

Numerous benefits or opportunities that telemedicine can offer have been identified, as well as certain negative aspects or challenges that difficult the adoption of this technology. In the following tables (see Tables 2-4), a summary of the founded advantages and disadvantages for patients, healthcare professionals, and the healthcare system founded in different sources is presented. [32] [63] [34] [64] [38] [65].

Table 2 Advantages and disadvantages of telemedicine from a patient point of view.

Advantages	Disadvantages
– Wide access to quality medical services – Convenient remote access – Time and cost savings by reducing travel for medical services – Availability of abundant medical information and improved self-awareness of health status	– Varying patient technological skills – Challenges due to physical limitations or conditions – Limited patient access to necessary technology – Quality concerns – Privacy and information confidentiality – Household infrastructure and skills limitations – Challenges in establishing a trusting doctor-patient relationship – Fear of receiving incorrect treatment

Table 3 Advantages and disadvantages of telemedicine from a healthcare professional point of view.

Advantages	Disadvantages
– Quality of healthcare Reduces long-term costs – Prevents system saturation – Direct communication between providers, distributors, and the healthcare system – Sustainability of the system maintenance – Enhances distributive justice	– Insufficient protocols, regulations, and guidelines – Hospital infrastructure development challenges – Resistance from insurance companies – Legal restrictions, permits, licenses, and liability concerns – Potential non-compliance with regulations – Limited access to ICT – Costly technology and training requirements – Equipment upgrades

Table 4 Advantages and disadvantages of telemedicine for the healthcare system.

Advantages	Disadvantages
– Efficient time management – Prompt and efficient patient care – Continuity of medical care through easy information sharing and communication – Medical education and training by facilitating knowledge exchange – Quick access to patient information – Collaborative work – Reduced risk of infection and disease transmission	– Reduced patient-professional relationship and inter-professional relationships – Resistance and fear of change – Limited knowledge and experience of medical personnel in new system implementation – Concerns about medical information quality – Inability to perform physical examinations

In summary, telemedicine presents a range of advantages and disadvantages. The tables reveal that both patients and healthcare professionals benefit from common advantages offered by telemedicine, including time-saving efficiency, access to information, quick retrieval of medical data, and the opportunity for medical education. Moreover, a shared concern for both patients and professionals are related with the quality of the information exchanged between them.

4.2 Overview of telemonitoring

4.2.1 What is telemonitoring

As previously mentioned in section 4.1.4 *Types and applications of telemedicine*, telemonitoring, or remote monitoring, digitally transmits disease-related and physiological data from patients' homes to healthcare centers [31]. It enables early detection of disease decompensation, reduces mortality and hospitalizations, and empowers patients [47]. Telemonitoring systems utilize sensors attached to the body or in the environment for contactless monitoring of vital signs [48]. This technology comes along with many advantages including reduced in waiting times, healthcare costs saving and eases the workload on medical staff [8].

4.2.2 Historical background, origin and development

The origin of vital sign monitoring dates back to the late 16th century when Galvani discovered muscle contractions in frog's legs stimulated by electrical impulses, event that led the way to the field of electrophysiology [66]. Matteucci's observation in 1842 revealed the electrical currents accompanying each heartbeat, expanding our understanding of cardiac activity [67]. Lippmann's capillary electrometer, invented in 1872, recorded bioelectric phenomena [67]. Waller applied the capillary electrometer to the human heart in 1887, founding cardiac electrophysiology [68]. Einthoven's work in the early 1900s led to the development of the electrocardiograph. Technological advancements in the 20th century resulted in portable electrocardiographs, such as the Holter ECG [69].

The integration of technology in healthcare, facilitated by the Internet, brought remote monitoring and transmission of vital data [23]. The 2000s saw accelerated development in vital sign monitors, including wireless systems capable of measuring multiple parameters [70]. Today, vital sign monitors utilize diverse sensor technologies and allow for real-time recording and remote access [70]. Breakthroughs in remote monitoring enable continuous evaluation using advanced communication and sensor technologies, offering a wide range of sensors for various vital signs control, both attached to the body and integrated into the environment. [48].

4.2.3 Most important vital signs to be monitored

The human body presents various physiological indicators that can be evaluated, including electrical signals and biochemical markers. These signals, once analyzed, provide valuable insights into overall health and how the body responds to external influences, improving our understanding of well-being [71]. Key physiological indicators include HR, respiratory rate (RR), BP, blood oxygen saturation (BOS), blood glucose levels (BGL), and skin or body temperature (BT). Additional data such as weight, activity levels, and sleep patterns are sometimes collected [48]. In the following sections, we will provide a brief explanation of each of these vital signs.

- HR: it is a standard vital sign, also known as pulse, that is routinely measured in all types of medical check-ups [72]. It provides important insights into a person's health status. [73]. The HR refers to the number of times the heart beats within a specific period, typically one minute and can be felt in different areas of the body where arteries are located, such as the wrist, neck, knees, or groin [73]. The normal resting HR for a healthy adult typically ranges between 60 and 100 beats per minute, but it can be influenced by factors like age, weight, physical activity, and medications. [72]. Monitoring pulse is crucial for detecting abnormal HR patterns, identifying arrhythmias, and anticipating potential heart attacks [74].

- RR: it is another key vital sign of the human body that refers to the number of breaths taken per minute. In adults, the normal respiratory rate ranges from 12 to 20 breaths per minute, while in children, it varies as they grow [75]. The speed, pattern, and depth of your breaths indicate how effectively your body is supplying oxygen to all vital organs and tissues [75]. Monitoring this parameter is essential as even slight changes in respiratory rate can be attributed to factors like nasal congestion or intense exercise. However, it can also serve as an indicator of serious respiratory conditions [72], such as chronic obstructive pulmonary disease, in which the respiratory rate increases as the body attempts to meet the elevated oxygen demand [75].

- BP: it is defined as the force exerted by the blood against the walls of the arteries when the heart pumps it [76]. This parameter is comprised of two numbers: systolic pressure and diastolic pressure. Systolic pressure refers to the pressure when the ventricles pump blood out of the heart during a heartbeat, while diastolic pressure is the pressure between heartbeats when the heart is at rest and filling with blood [77]. BP is a dynamic parameter that fluctuates throughout the day based on various activities. However, there are established values that indicate good health. For most adults, a normal BP reading is below 120 over 80 millimeters of mercury (mm Hg), expressed as the systolic pressure over the diastolic pressure (120/80 mm Hg) [76]. Any reading outside of these ranges is considered abnormal and may indicate hypertension if the values are above the limit, or hypotension if they are below [76].

- BOS: it is a valuable vital parameter that indicates the amount of oxygen being transported by red blood cells [75]. The body actively regulates this oxygen level since maintaining a precise balance of oxygen-saturated blood is crucial for overall health [70]. A normal reading of blood oxygen saturation, when using a pulse oximeter (SpO_2), falls between 95 percent and 100 percent [70] [78]. Values below the normal range can have severe implications for the body's functioning.

- BGL: this parameter refers to the amount of sugar present in the bloodstream [79]. Glucose plays a crucial role in maintaining optimal bodily functions. Keeping glucose levels within the normal range is vital for the body to function efficiently and stay healthy [79]. Before eating, a healthy range is typically between 90 and 130 milligrams of sugar per deciliter of blood (mg/dL) and, after one or two hours, it should ideally be below 180 mg/dL

[79]. Deviating from these values, either higher or lower, can have serious implications for the body, as seen in conditions like diabetes where blood sugar levels are consistently elevated [80]. Over time, such imbalances can lead to severe complications, including damage to the eyes, kidneys, nerves, and other vital organs [80].

– BT: it refers to the outcome of the balance between heat production and heat loss in the body, and its measurement is vital to prevent the dysfunction of various bodily elements due to high temperatures [81]. Normal BT varies depending on the individual, age, activities, and the time of day, with it typically being lower in the early morning. The widely accepted average normal BT is generally around 37°C [82], although some studies have shown that it can be considered within the appropriate range of 36.1°C to 37.2°C [83]. Monitoring this parameter is crucial, as a temperature above the established normal values is often an indicative sign of fever caused by an infection or illness [83] and can also be useful in monitoring the effectiveness of a treatment [84].

4.2.4 Technologies employed to monitor, diagnose and prevent diseases

The rapid advancement of technology has led to a significant increase in the availability of devices and systems specifically developed for patient monitoring. These solutions encompass a diverse range of approaches. In this section, information of those approaches will be provided. Based on the classification of devices mentioned in [85] and [86], the following organization (see Figure 11) has been adopted, classifying the technology into four different types based on the method of integration in the patient's body: portable, attachable, implantable, and ingestible devices.

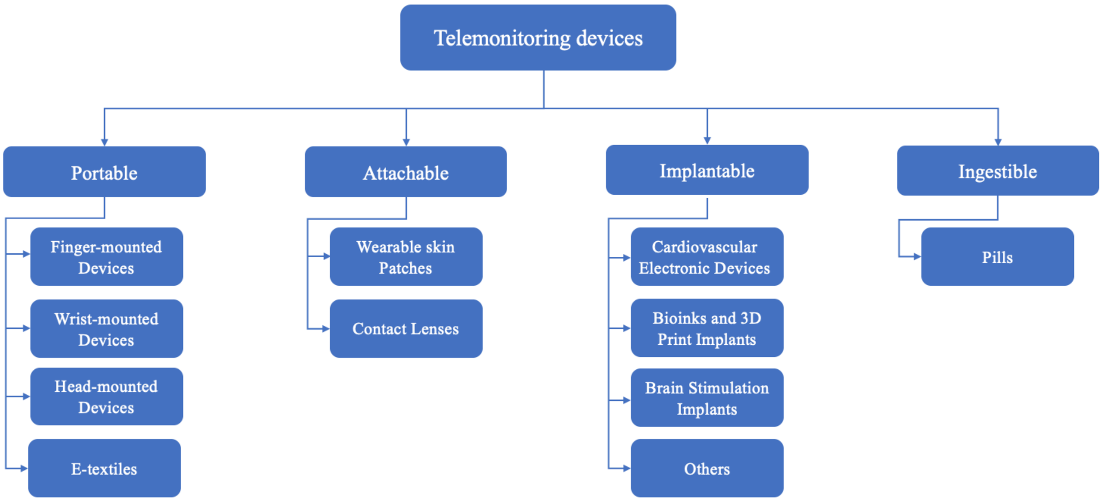

Figure 11 Classification of telemonitoring devices.

Portable devices

The advent of emerging technologies has revolutionized the delivery of traditional healthcare, introducing various devices and systems that continuously monitor patients [87]. Wearable devices play a vital role in monitoring and recording real-time information on an individual's physiological condition and motion activities. This information is not only essential for managing a patient's current condition but also for proactively identifying and preventing potential diseases [88]. Portable devices can be classified into the following categories: finger-mounted devices, wrist-mounted devices, head-mounted devices and e-textiles or smart clothes. [85]. Following, a summary of portable devices is provided in Table 5.

Table 5 Summary of portable devices.

Portable devices		
	Monitoring	**Physiological parameters**
Finger-mounted	Cardiovascular signal, sleeping patterns, BT	HR, heart rate variability (HRV), RR, BP
Wrist-mounted	Cardiovascular signal, sweat contents, tremor patterns, BT	HR, RR, BGL, BP, BOS
Head-mounted	Sweat contents, physical activity	BGL, vitamins, lactate
E-textiles	Cardiovascular activity, sweat contents, physical activity, BT	HR, RR

Finger-mounted devices

A remarkable latest advancement on the field of portable vital sign remote monitoring devices is the called OURA Ring. Developed by OURA, this non-invasive finger-mounted deice employs sensors to monitors vital signs including HR, BT, and different activity levels. It is also capable of tacking sleep patterns since equipped with built-in accelerometer. One of its most remarkable features is its ability to remotely monitor BP indirectly by analyzing HRV. This meassure evaluates the variations in the time intervals between heartbeats, providing valuable insights into overall health and well-being. By continuously tracking HRV, the OURA Ring can detect patterns and trends that may impact BP, such as stress, sleep deprivation, or unhealthy eating habits. [89] A study was conducted in 2020 with the aim of validating the accuracy of this device in measuring signs like HR and HRV Involving 49 adult healthy subject, the results obtained sowed haw OURA ring offered HR and HRV readings of 99.6% and 98% accuracy respectively [90].

Wrist-mounted devices

Electrocardiogram (ECG) and photoplethysmography (PPG), which will be explained with more detail later, are widely used in wearable technology to monitor heart function. ECG measures the heart's electrical activity, while PPG uses light to measure blood volume. While ECG sensors have traditionally been implemented as skin patches, there is an increasing number of wrist-worn devices available, such as the Apple Watch 4 or 5, that can measure heart rhythms. These devices utilize predictive algorithms to monitor heart activity, however, the measurement is not continuous. In contrast, PPG can be continuously measured on the wrist using a watch-like device. [91]. Garmin watches are another example of wrist monitors available in the market that, like Apple watches, monitor heart function. However, there are other devices offered by companies like Biobeat and Biostrap that not only provide the mentioned capabilities but also allow for skin temperature and BOS monitoring. Additionally, wrist monitor watches from WHOOP company include an Early Detection Algorithm for predicting viral illness or wellness [91].

Apart from health or vital sign monitoring, these technologies also allow for disease monitoring and diagnosis. At present, there have been some developments in the neurodegenerative field. Researchers from Apple Inc. in Cupertino, California have created the Motor Fluctuations Monitor for Parkinson's Disease (MM4PD), an Apple Watch application designed to accurately capture patterns of resting tremor and choreiform dyskinesia, which are common side effects of L-dopa treatment. This innovative smartwatch allows for continuous monitoring of symptoms and for data transmission to healthcare providers. By analyzing the collected data, more personalized treatment plans can be developed for individuals with Parkinson's disease [72].

Additionally, portable device technology can also be applied in diabetes care. GlucoWatch has developed the first commercially available non-invasive glucose monitor. Approved by the FDA, this device extracts glucose concentration from skin interstitial fluid using reverse ionophoresis. [11]. Another example is the use of wearable glucose monitors that transmit data to Apple devices like Apple watches through HealthKit. This innovation, pioneered by the Stanford School of Medicine, enables healthcare providers to monitor patients' glucose trends between visits and communicate through MyChart, an Epic EHR and PHR system. This integration enhances provider workflow, patient communication, and overall quality of care [92].

Also, sensors from smart wrist watches enable elderly patients to independently engage in daily activities. Remote health monitoring applications support tasks like sitting, standing, using the bathroom, watching TV, reading, and sleeping with minimal disruption. These sensors have minimal impact on the user's activities, making them a convenient option. [48].

Head-mounted devices

Among the various types of head-mounted devices, smart glasses belong to the category with the most extensive range of research. Alongside helmets and caps, these devices are currently being utilized in surgical procedures, imaging technologies, and simulations. However, when it comes to commercial head-mounted wearables, particularly smart glasses, they are still lacking the level of maturity seen in wrist-worn devices [11]. Smart glasses have been suggested for facilitating the monitoring of vital signs. To be useful, smart glasses require a customized application and must be integrated in the interacting work system which is defined as an environment that encompasses one or more individuals, tasks, technology and tools and organization [93].

According to different articles, several glasses-based devices have been developed to ensure different things, such as the development of a wearable tear bioelectronic platform using eyeglasses [94]. The integrated system monitors tear biomarkers using a microfluidic electrochemical detector which enables real-time measurement of alcohol, glucose, and vitamins in tears. Other approaches include biosensors that can be worn on eyeglasses. An example is a biosensor that enables noninvasive and accurate measurement of lactate levels in human sweat during physical exercise, providing valuable information regarding the body's energy expenditure and anaerobic threshold. This technology holds promise for applications in physical activity and biomedicine [95].

Human tears, along with saliva and sweat, are crucial biological fluids comprising proteins, electrolytes, metabolites, and predominantly water. These components make tears valuable for diagnosing human metabolites [11]. Innovations in the filed have enabled the non-invasive monitoring of tear physiology [96]. A representative example of this are glasses capable of measuring glucose levels using tears, offering a less invasive alternative to traditional finger-prick methods. This system utilizes glucose oxidase enzyme reacting with tears. The glasses have a biosensor that detects and measures chemical reactions, providing signals based on substance concentration [97].

E-textiles

Wearable health monitoring systems have revolutionized healthcare by integrating flexible sensors, electronics, and communication components into textiles. This innovative approach allows for comfortable and unobtrusive monitoring of physiological signals using conventional fabric manufacturing techniques like weaving, knitting, embroidery, and stitching [71]. Smart textiles provide a versatile platform for developing wearable on-body electrodes capable of measuring various physiological signals, including ECG, electroencephalogram (EEG), galvanic skin response (GSR), and electromyography (EMG). These sensors integrated into the fabric enable continuous monitoring of vital signs such as temperature, HR, and respiration, offering valuable insights into patients' health [98].

Advancements in textile technology have led to the integration of PPG sensors into wearable textiles using flexible plastic strips or embroidered optical fibers [71]. These sensors enhance the accuracy of measurements by analyzing different tissue depths using fiber-based light sources and detectors. Other development in the smart-textile field is Intexar, a textile developed by Dupont capable of monitoring respiratory functions [99], or sensing fibers from MesoMat, which enable for real-time monitoring [100].

The market provides a variety of wearable health monitoring devices, such as arm sleeves (AIO), compression shirts (Hexoskin), and bands (Microsoft) [91] [101]. These devices are designed to measure parameters like oxygen saturation, HR, HRV, respiration rate, calories burned, and sleep patterns. They are particularly beneficial for fitness enthusiasts and individuals who desire personalized health tracking.

Smart textiles can also be useful in disease diagnosing. In the field of cancer detection, wearable technology has introduced devices like the Cyrcadia Breast Monitor (CBM), a non-invasive wearable device that records thermodynamic metabolic data from the surface of the breast skin [102]. By analyzing this data, the CBM can identify the presence of breast tissue abnormalities, potentially providing early confirmation of changes before resorting to invasive methods like biopsies [102].

Attachable devices

Technological advancements in the medical field have promote the development of smart adhesive patches. These patches, equipped with integrated electronics, provide valuable information, and serve as reliable platforms for monitoring health conditions and delivering advanced medication solutions [103]. Known for their adaptability and flexibility to human skin, patches offer accurate sensing capabilities while maintaining the user's natural mobility and comfort. This attribute plays a crucial role in defining the functionality of such devices [86]. In this study, wearable skin patches have been divided in two groups: wearable skin patches and contact lenses. Following, a summary of attachable devices is provided in Table 6.

Table 6 Summary of attachable devices.

Attachable devices		
	Monitoring	**Physiological parameters**
Wearable skin patches	Cardiovascular activity, sweat contents, BT, migraine	BGL, metabolic biomarkers
Contact lenses	Chemicals, eye signals	BGL, lactate, vitamins, intraocular pressure

Wearable skin patches

Smart skin adhesive patches come as a crucial tool for diverse medical applications [104]. These patches integrate electronics and multiple sensing modalities into miniaturized, skin-conformal wearable devices simplifies monitoring, providing a remarkable platform for monitoring health conditions, facilitating intelligent medication, and enhancing patient comfort. [103] [105] They consist of a sensor layer placed on a flexible and stretchable substrate, directly applied to the skin, converting physical information into electrical signals [106]. By simultaneously tracking vital signs and biomarker levels, skin patches offer valuable insights for disease prevention, diagnosis, and treatment. [106]. In this section, a distinction has been made between patches used for temperature monitoring and those used for body fluids monitoring.

BT monitoring is essential since high temperatures are often an indicative sign of fever caused by an infection or illness [83]. To accomplish this, adhesive patches integrate digital temperature sensors for reliable and continuous core BT monitoring [91]. Companies like Gentag, specialize in patented skin patch systems with diverse capabilities. Their offerings include low-cost disposable fever patches for non-invasive BT monitoring, pain-free diabetes monitoring platforms utilizing flexible sensors, and cosmetic patches that track environmental conditions and physiological factors. These patches connect to smartphones, providing real-time information and alerts for improved health management [107].

The monitoring of body fluids is also crucial in order to effectively assess the impact of daily activities on the body's physiological responses. By tracking both metabolic and hemodynamic parameters, a deeper understanding can be gained, enabling the early detection of abnormal physiological changes. [105]. Innovative solutions like the Discovery Patch Sweat Collection System by Epicore Biosystems simplify the capture, collection, and analysis of sweat biomarkers, offering valuable information for clinical trials and research [108]. The latest advancements include the E-skin patch developed by scientists from the Terasaki Institute. Utilizing a gelatin-based substrate called GelMA, this patch allows continuous monitoring of vital signs and metabolic markers by stimulating sweat excretion and extracting interstitial fluid [106].

This emerging technology can also be applied to other medical fields such as the neurological. An example is the case of wireless chip-based patches developed by Theranica, which offer personalized and portable care for acute migraine treatment. Controlled via smartphone apps, these patches deliver electrical pulses to sensory nerves, providing an innovative therapeutic approach [109].

Contact lenses

Smart contact lenses have revolutionized the monitoring of physiological information using optical and electrical methods. As previously mentioned, human tears, saliva, and sweat contain essential components such as proteins, electrolytes, metabolites, and water. Analyzing these components provides valuable insights into human metabolites, enabling reliable health assessments and disease diagnosis [110].

As many other telemonitoring devices, lenses can also help in diabetes monitoring and diagnosis. Some lenses can track chemicals like lactate and glucose, measure tear fluid conductivity, and monitor transcutaneous gases in the eye's mucous membrane [104]. One example is a multifunctional flexible contact lens made from inorganic magnetic oxide nanosheets, enabling real-time diagnosis of chronic eye diseases by simultaneously monitoring glucose levels, eyeball movement, and intraocular pressure [111]. Photonic microstructure-based sensors in contact lenses offer point-of-care quantitative glucose measurements, benefiting diabetes monitoring and diagnosis [112]. Additionally, a research team at POSTECH has developed a smart contact lens integrating an intraocular pressure (IOP) sensor and a flexible drug delivery system. This lens addresses the continuous IOP management needs of glaucoma patients, potentially enabling automatic monitoring and control for improved quality of life [113].

According to the WHO, glaucoma is one the most prevalent causes of blindness globally [114]. Fortunately, smart lens technology is algo advancing in this area. An example is the SENSIMED Triggerfish continuous ocular monitoring system that incorporates a smart contact lens capable of tracking changes in ocular volume over 24 hours. This technology contribute to aiding physicians in managing glaucoma and making treatment decisions [115].

Latest advancement in the field is the integration of virtual and augmented reality in wearable devices which has led to significant advancements. A noteworthy example is the upcoming Mojo Vision Lens developed by Metamandrill, a smart contact lens that combines augmented and virtual reality capabilities. This innovative lens features eye tracking, advanced displays, and an intuitive user interface controlled by eye movements. With diverse applications ranging from vital sign monitoring to assisting athletes and individuals with physical disabilities, these devices offer a wide range of benefits for various tasks and activities [116]. Innovega is also making strides in this field, developing smart contact lenses and glasses to enhance vision for individuals with visual impairments, including the legally blind, offering restored independence and improved quality of life [117].

Implantable devices

Wearable devices have undergone a gradual evolution, ranging from accessories and integrated clothing to body attachments and inserts. The advancement of electronics, biocompatible materials, and nanomaterials has played a significant role in the development of these devices that can either be temporally o permanently implanted [118]. These devices incorporate small sensors and biomedical technology, enabling improved diagnosis, prognosis, and enhanced quality of medical services. [104]. The aim of implantable technology is to reduce pain and discomfort during medical procedures while offering patient-friendly diagnostics and treatments [119]. By utilizing innovative materials and point-of-care sensing platforms, these devices with special functionalities can be efficiently created [119]. Implantable devices can be made of various materials, including human tissues and exogenous materials such as electrochemical-based, nanomaterial-based, or fiber-based devices [120]. Additionally, modern implantable sensors now utilize wireless communication for external data processing, replacing the need for wired connections [86]. In this section, and following the categorization made in [86], implantable devices have been divided into the following groups: cardiovascular implantable devices, bioinks and 3D print implants, brain stimulation implants and other implantable devices. Following, a summary of implantable devices is provided in Table 7.

Table 7 Summary of implantable devices.

Implantable devices		
	Monitoring	**Physiological parameters**
Cardiovascular	Cardiovascular signal	Heartbeats, pulmonary artery (PA) pressure
Bioinks and 3D implants	Interstitial fluid	GBL, pH, electrolytes
Brain stimulation	Brain activity	others
Others	Intercellular fluids, frequency signals	GBL

Cardiovascular implantable devices

Cardiovascular implantable electronic devices have expanded capabilities in recognizing cardiac changes related to heart failure (HF) and providing valuable information for early recognition and management [120]. Telemonitoring and wireless pulmonary artery pressure monitoring have shown potential in reducing re-admission risk and managing heart failure patients [121].

The most common cardiovascular implantable devices are pacemakers which regulate the heart rate and rhythm by delivering electrical pulses [122]; implantable cardioverter defibrillators (ICDs) or ICDs that detect and correct irregular heartbeats through electric shocks [123]; biventricular pacemakers which help synchronize the heart chambers for more efficient pumping [124]; cardiac loop recorders which are a long-term monitoring device that detect subtle changes in the heartbeat and transmit this information to healthcare providers, enabling early diagnosis and potential prevention of heart diseases [125]. Another approach to monitor heart dysfunctions is through BP monitoring, such as the CardioMEMSTM HF System, which utilizes a passive LC sensor implanted in the pulmonary artery to monitor pressure changes [86].

Bioinks and 3D Print implants

Medical 3D printing has evolved from being just a dream to becoming a reality. It offers great potential by enabling the creation of personalized drugs, rapid production of medical implants, and changing the way in which health professionals plan procedures. Patient-specific 3D-printed anatomical models are becoming more and more valuable tools since they allow for treatment personalization [126].

Bioink is a biomaterial used in 3D bioprinting used to create living cells and growth factors. The selection of an appropriate bioink is key for achieving successful bioprinting. Several important properties of this material must be considered to ensure effectiveness in the biological printing process [127]. These properties include rheological properties (such as viscosity, shear rate, and shear stress), mechanical properties (such as pliability and elasticity), and biocompatibility, which refers to the biomaterial's ability to interact harmlessly with the recipient's cells [128]

Some applications of bioprinting include tissue engineering and regenerative medicine, 3D organ printing and transplantation, drug toxicology screening, drug printing, and clinical research, among others. However, many of these applications are still in the developmental stage and have not been implemented widely [129].

Brain stimulation implants

Technological advancements in electronic devices and micro-machining have led the way to the development of highly capable wireless implantable micro-devices. Apart from other implantable applications mentioned earlier, these advancements have also extended to the field of neurology, enabling the creation of brain implants with the ability to stimulate or sense brain activity [36]. A commonly known procedure is Deep Brain Stimulation (DBS), where electrodes are surgically implanted in specific regions of the brain to regulate abnormal impulses as well as regulate the activity of targeted cells and chemicals [35]. The level of stimulation is generally adjusted by a pacemaker-like device positioned under the skin in the upper chest [35]. This therapy is usually employed to treat Parkinson’s disease [130]. It addresses the movement symptoms of the disease and contributes to reduce side medication effects. However, it is important to note that it is a reliever therapy meaning that it cannot cure the movement disorder [130].

Other implantable devices

Advancements have been also made in developing devices for subcutaneous wearable monitoring of intercellular fluids (ICF), particularly for monitoring glucose concentration in diabetic patients [11]. Another field where this technology has had a significant impact is audiology, particularly with cochlear implants. A cochlear implant is an electronic device designed to restore auditory perception in individuals with severe hearing. It consists of an external component positioned behind the ear that captures sound signals which are sent to an internal component surgically implanted beneath the skin. The transmission if this signal stimulates electrodes in the cochlea. The auditory nerve transmits the signals to the brain, allowing the perception of sound [131]. A leading company in this field is Cochlear, known for offering a diverse range of implants and electrodes to address any form of hearing loss. Some of their most extended products are Cochlear Nucleus, Osia, and Baha Systems. [132].

Ingestible devices

As seen throughout this section, the progress in medical technology has led to the creation of devices and systems with remarkable capabilities. However, despite their numerous advantages, these devices often face limitations when it comes to accessing deep-seated areas within the body or niduses. Ingestible biosensors, known as ingestible biosensing capsules (IBCs), offer an alternative to wearable sensors for monitoring health indicators inside the body [129]. These capsules can travel through the gastrointestinal tract, reaching major organs and detecting a wide range of biomarkers which provide information about the gut's health [129]. In general, devices that interact with living organisms are typically made of materials such as metals, ceramics, silicon, or plastics, which often require invasive procedures for long-term monitoring. However, with advancements in research, biocompatible materials like hydrogels are being proposed as a non-invasive alternative for their implantation [133]. Equipped with advanced imaging and sensing techniques, these ingestible robots have the capability to monitor and diagnose diseases, offering valuable insights into gastrointestinal disorders and their underlying mechanisms [134]. They can monitor various parameters such as pressure, pH, temperature, and utilize tissue imaging techniques, among others [134] Following, a summary of ingestible devices is provided in Table 8.

Table 8 Summary of ingestible devices.

Ingestible devices		
	Monitoring	**Physiological parameters**
Pills	Biomarkers, gastrointestinal condition, drug protection	pH, BT

The most common form of ingestible biosensors are pills. The Medtronic PillCam SB 3 capsule serves as an example of this format for tissue imaging. Its purpose is to determine the presence of any obstruction in the small intestine before conducting an endoscopy. This capsule utilizes advanced optics and imaging capabilities to capture high-quality images of the intestinal mucosa. It also incorporates innovative features, including adaptive frame rate technology, which adjusts to the unique motility patterns of each patient. Furthermore, it provides essential tools for recording and interpreting the study results [135].

An example of a biosensor for monitoring vital signs such as temperate is e-Celsius, a miniaturized electronic ingestible capsule that continuously transmits core temperature data. It communicates with a dedicated monitor in real time, allowing data recording and triggering alerts if thresholds are exceeded. This single use device counts with its own memory and is removed naturally after 24-48 hours. [136]

Other biosensors for drug delivery control have been also developed. One example is the RaniPill capsule, designed by Rani Therapeutics, with the purpose of protecting the drug until it is injected. The concept behind this capsule is that it remains intact while passing through the stomach, where acids can degrade drugs, allowing its release into the highly vascularized intestinal wall for fast absorption. [137]

4.3 Case Study: Arterial hypertension telemonitoring

4.3.1 Arterial hypertension: definition, types, phenomena, and other key features

In this first section, arterial hypertension will be described, including its different types, phenomena observed during evaluation, and important characteristics that define BP measurements in this context.

Definition and types

The current definition of hypertension (HTN) is when systolic BP (SBP) values are 130mmHg or higher and/or diastolic BP (DBP) is more than 80 mmHg [138]. In the previous section (4.2.3), vital signs, including BP, were discussed in detail, explaining systolic and diastolic BP. The definition and categorization of hypertension have evolved over the years, but there is a consensus that persistent BP readings of 140/90mmHg or higher should be treated, with the target therapeutic goal being 130/80mmHg or lower [139]. According to the guidelines of the European Society of Cardiology and European Society of Hypertension (ESC/ESH guidelines), optimal, normal, high BP, and different grades of hypertension are categorized as shown in Table 9. [140]

Table 9 Blood pressure classification and hypertension grades definition

Category	SBP (mmHg)		DBP (mmHg)
Optimal	< 120	and	< 80
Normal	120-129	and/or	80-84
High normal	130-139	and/or	85-89
Grade 1 Hypertension	140-159	and/or	90-99
Grade 2 Hypertension	160-179	and/or	100-109
Grade 3 Hypertension	>= 180	and/or	>= 110
Isolated systolic Hypertension	>= 140	and	< 90

Key features

Before diving into the description of devices employed to telemonitor BP and, therefore, gain a better understanding of each one of them, it is essential to first comprehend some important aspects of the evaluation of this vital sign. Measurements of BP can be categorized based on various factors. In this study, we will consider the following aspects: the setting where the measurement is conducted (see Figure 12), the frequency of measurements (see Figure 13), and the methodology employed in the evaluation (see Figure 14).

Measurement location

In terms of BP measurement, there are two main methodologies based on the setting in which the measurement takes place (see Figure 12).

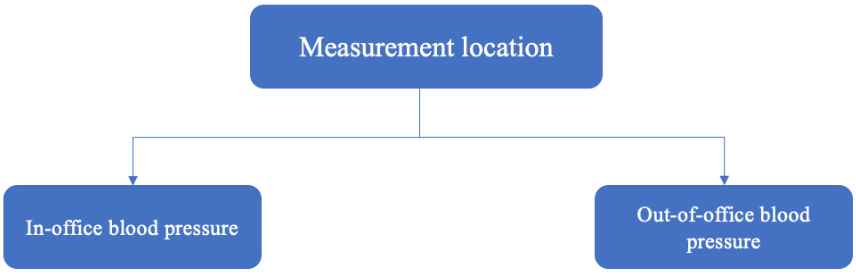

Figure 12 classification of blood pressure measurements based according to the evaluation.

The first approach is known as office BP (OBP) measurement or conventional BP evaluation [141], which involves taking BP readings in a doctor's office or clinic [140]. The second approach is referred to as out-of-office BP measurement, where the readings are taken remotely outside of the clinical setting [140]. Since this project is dedicated to telemedicine, particularly to telemonitoring, the focus will be specifically on the typology of out-of-office BP measurement. Unlike office measurements, which typically involve only a few evaluations during a doctor's visit taken via different methods (auscultatory, automated, unattended with patient alone in the office) [142], out-of-office measurement involves taking multiple ones over a period of 24 to 48 hours [143]. This fact explains why out-of-office methodology is characterized by obtaining more accurate and realistic BP readings of patients, as they are taken in situations that reflect their everyday life rather than in a clinical environment [140]. Overall, it provides more important adjunct information [144].

Measurement frequency

According to [145], out-of-office BP measurements can be conducted through two different approaches, home BP monitoring (HBPM) or ambulatory BP monitoring (ABPM) (see Figure 13).

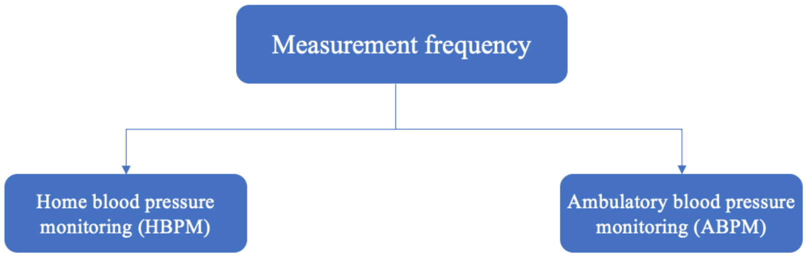

Figure 13 Classification of blood pressure monitoring according to the frequency of taken measurements.

HBPM, also known as self-BP monitoring, entails monitoring performed by the patients themselves at home. In this practice, automatic BP oscillometric-based monitoring devices that record readings taken from the patient's brachial artery are used [146], rather than conventional BP cuffs which imply manually taken measurements. [147]. This out-of-office approach to monitor BP can confirm the diagnosis of hypertension after an elevated office BP reading and can identify patients with white coat hypertension or masked hypertension [Articles_AH23].

ABPM involves patients wearing a portable monitor for a period of 12 to 24 [146] and, in some cases, even up to 48 hours [147]. This approach provides extensive information since BP data is recorded at regular intervals, usually every 20 to 30 minutes [146], including nocturnal BP readings and short-term BP variability [147]. Patients can carry out their daily activities and even sleep while the measurements are being taken. In addition to the HBPM methodology, this second manner of evaluating BP is also indicated for hypertension diagnosis specially to detect whit-coat and mask hypertension condition [148].

Measurement methodology

Devices for monitoring BP remotely employ different techniques to obtain this vital sign readings. Among the most common and frequently used ones are the following: Oscillometry, applanation tonometry and photoplethysmography (see Figure 14) [149]

Oscillometry is a common method for measuring BP using automatic cuff

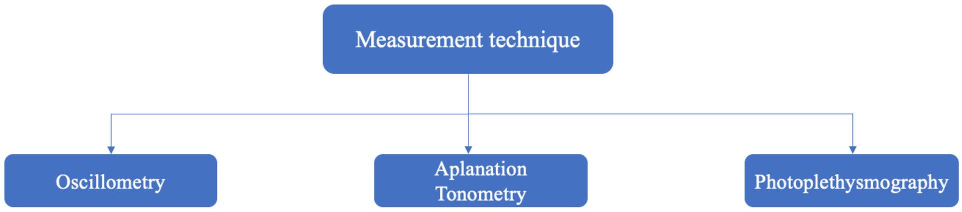

Figure 14 Classification of blood pressure monitoring according to the methodology employed to carry out the measurement.

devices [150]. It can potentially be extended for cuff-less and calibration-free monitoring via smartphones [150]. The method involves applying external pressure to an artery and measuring the pressure to detect blood volume oscillations [150]. When a cuff device is used, inflating it stops arterial blood flow, and deflating it detects pressure differences between the cuff and artery, creating a pulse wave. [151]. BP is then estimated based on the oscillation amplitude using algorithms. There are different algorithms: the maximum amplitude estimates mean BP, the fixed ratio estimates diastolic and systolic BP, and the derivative algorithm estimates diastolic and systolic BP based on slope. [152]. The method has advantages such as not requiring a transducer above the brachial artery and being less affected by external noise (except for low-frequency vibrations) [153]. However, it presents limitations in accuracy, and it is not reliable during physical activity due to movement noise. It requires validation for specific populations and subject to ensure reliable readings [151]. Oscillometry is widely used in current office, home, and ambulatory BP measurement devices [154]

Applanation tonometry is a noninvasive technique for measuring BP that consists in applying force to the artery to assess the pulsatile displacement of the vessel wall [149]. It employs a pressure sensor to gently compress the artery, eliminating tangential forces and capturing the outward force of intravascular BP [155]. Normally, the pressure is applied to the radial artery, however, other arteries like the carotid, brachial, and femoral arteries can also be employed [153]. Nonetheless, it should be noted that this technique, originally designed for beat-to-beat wrist BP monitoring, requires individual calibration and is not suitable for routine clinical settings. [156].

Photoplethysmography (PPG) is a non-invasive method that measures the pulsations of blood volume in tissue, providing an estimation of arterial pressure pulse [157]. This third approach utilizes a light-emitting diode (LED) and a photodetector to measure the variations in blood volume in peripheral tissues. By emitting light into the skin and detecting the reflected or transmitted light, PPG captures the pulsatile changes in blood flow, primarily driven by the heartbeat. [158]. These pulsations are modulated by the volume changes in the blood vessels and can be used to derive information about the cardiovascular system, such as HR and BP. Transmissive sensors used in PPG technology are commonly used on fingertips, which have less thickness, while reflective sensors are more practical on body parts like the wrist, arm, chest, and forehead, where the thickness of the tissue makes transmissive sensors impractical. [155]

Phenomena

BP is a highly dynamic vital sign that is easily affected by external factors, leading to fluctuations throughout the day, resulting in significant variability. As a result, during the process of measuring BP, a range of different phenomena can occur [159]. In first place, white-coat hypertension, also known as isolated office hypertension [144], refers to the condition where BP is elevated in a medical office but normal when measured by ABPM, HBPM, or both [160]. In this case, the difference between the higher office and the lower out-of-office BP is referred to as the "white-coat effect" and is believed to mainly reflect the pressor response to an alerting reaction elicited by office BP measurements by a doctor or a nurse, although other factors are probably also involved [160]. The prevalence of this phenomenon in the general population is approximately 13% [159]

In contrast, mask hypertension or isolated ambulatory hypertension refers to untreated individuals who have normal BP in the office but exhibit elevated readings when measured by HBPM or ABPM [160]. It is more commonly observed in young people, males, smokers, overweight or diabetic individuals, and those experiencing anxiety or stress [159].

4.3.2 Technologies employed to telemonitor blood pressure

This section presents a wide range of devices used for remotely monitoring BP or, which is the same, out-of-office BP monitoring devices. Following the same organizational scheme included in section 4.2.4 (see Figure 9), the arrangement of different devices employed to evaluate BP is presented in Figure 15.

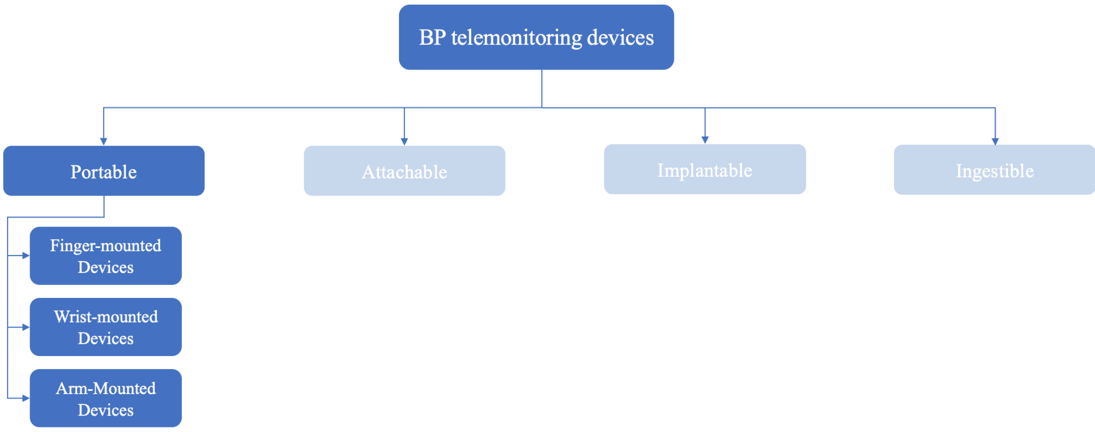

Figure 15 Classification of blood pressure telemonitoring devices.

As it can be seen in Figure 10, only portable devices are available for BP telemonitoring. Next, a description of the technologies is provided.

Portable devices

As previously mentioned, BP is a highly variable parameter that fluctuates throughout the day. Consequently, the utilization of portable devices for obtaining BP measurements at different times of the day holds great value for the effective management of hypertension [161]. In the next section, we will describe some of the most used portable technologies in this regard.

Finger-mounted devices

A method used in many finger-mounted BP monitoring devices is the one introduced by Penaz called the volume clamp method for continuous non-invasive BP monitoring [153]. This method utilizes a small finger cuff with an infrared light source and receiver to estimate blood volume in the finger. By controlling the pressure in the cuff, the blood volume in the finger is kept constant and equivalent to the unloaded vessel state determined during calibration. The oscillations of the controlling pressure closely reflect the pressure in the arteries. [162]. The Finapres NOVA device is a non-invasive system that utilizes a finger cuff to monitor hemodynamics accurately and continuously, providing precise BP readings without the need for invasive methods. Moreover, the system is flexible and customizable, allowing for the integration of software applications and hardware configurations to meet the specific needs of your medical practice. [163]

Wrist-mounted devices

Wrist- mounted devices are non-invasive Cuffless BP monitors that measure systolic and diastolic BP without an inflatable cuff. They are easy to use, safe, and relatively accurate for resting-state BP measurement [156].

An example of this technology is the BPro device, which utilizes the applanation tonometry technique to collect real-time pulse wave data from the radial artery. This non-invasive system ensures reliable and precise measurements of arterial pulses. With its user-friendly interface and bundled software applications, BPro has the capability to establish continuous 24-hour ABPM and arterial pulse wave measurement as the standard practice for early healthcare management of hypertension and associated conditions. This wrist-worn portable watch is lightweight, convenient, and offers accurate BP readings without interfering with daily activities and night sleep. [164]

Arm-mounted devices

Arm-mounted devices are a non-invasive approach for measuring BP that enables both intermittent and continuous readings. Typically, an occlusive upper arm cuff is utilized for intermittent non-invasive monitoring. When employing such systems, BP readings can be automatically obtained using oscillometry technique [165]. According to

Forbes Health, some of the top devices in this category considering features such as price, accuracy, data storage ability and usability are the followings [166]: iHealth clear wireless BP monitoring device provides comparative results that can be stored, tracked and managed in a smartphone app via wifi [167]; Omron Platinum wireless upper arm BP monitor enables the acquisition of accurate data and allows the sharing of information through the Omron Connect app, via Bluetooth technology. This device can store up to 200 BP readings for two separate users, with a capacity of 100 readings per user. [168]; Oxiline Pressure X Pro BP monitor that uses advanced technology to provide accurate readings. Apart from including an easy-to-read display, it has capacity for storing up to 120 readings, which allows for tracking health condition.

4.4 Interview: Hypertension and actual diagnosing challenges

To provide further information in support of the content presented throughout the work, an interview was conducted with Dr. José María Masuet Iglesias, director of the Basic Health Area in Verge del Toro, Mahón, Menorca. Next, the questions asked during the interview with the corresponding answers are provided.

1. In your opinion, what do you see as the primary challenge in BP measurements? *The main challenge in measuring BP lies in the significant variability observed across different types of measurements throughout the day. For instance, when doctors request patients to provide a record of their BP taken at home, in most cases, the results tend to be satisfactory as the measurements are taken in a calm and stress-free environment. However, upon re-evaluating BP during a clinic visit, it becomes apparent that, in many instances, the values are considerably higher. This notable discrepancy underscores the need for a continuous monitoring mechanism or device.*

   It is important to emphasize that the fluctuation of BP throughout the day necessitates multiple measurements to accurately assess a patient's condition. Essentially, continuous monitoring throughout the day is required to obtain precise data that can determine whether medication is required or not. Consequently, it is crucial to have a reliable device that can provide accurate *readings throughout the day while also being convenient and comfortable for patients to always carry with them.*

2. Given the complexities you mentioned earlier, would you characterize the diagnosis of conditions associated with BP, such as hypertension, as a challenging aspect in medical practice? *BP is one of the most dynamic physiological parameters that fluctuates throughout the day in response to various external factors, which adds complexity to the diagnosis of related diseases. A helpful example to better understand this concept is the diagnosis of diabetes. BGL vary during the day, typically rising after meals under normal conditions. However, in individuals with diabetes, blood sugar levels remain chronically elevated in type 1 diabetes or take longer than usual to regulate and reach a balanced state in type 2 diabetes. As a result, diagnosing this disease is relatively straightforward, as anyone with consistently high BGL without recent food intake could be considered a potential candidate for the condition.*

   On the other hand, assessing BP is a complex process. Even if someone appears healthy and has normal BP levels at a given moment, their BP can be influenced by multiple factors throughout the day due to their environment and lifestyle. Consequently, they may experience higher BP levels than what is considered normal, especially if these situations occur frequently. Over time, this sustained elevation can lead to organ damage, even without a formal diagnosis of hypertension. The question arises: What does it really mean to be hypertensive? Is it when the BP is consistently high at rest, or is it when the body is exposed to an environment that triggers hypertension? If a person already has elevated BP at rest and is also exposed to a challenging environment, their hypertension will have a more significant impact. Similarly, if the environment itself causes a patient to experience high BP, even if it's not consistently high at rest, they can still be affected by hypertension.

   This complexity highlights the challenges involved in diagnosing conditions such as hypertension. Merely measuring BP during isolated moments that do *not fully reflect one's typical lifestyle, like sitting calmly on the couch after a stressful day, or sporadically taking readings in scenarios that better represent daily life, such as during work hours, may not provide sufficient information.*

Due to the complexity of obtaining reliable data in relation to BP, it becomes apparent that there is a substantial underdiagnosis, which is concerning. To achieve an accurate diagnosis and identify candidates suffering high BP peaks due to their lifestyle to prevent diseases in the future, continuous monitoring of BP is necessary. This entails regular and ongoing measurements to capture fluctuations and properly evaluate cardiovascular health.

3. Considering everything discussed earlier, would it be accurate to say that lifestyle external factors have an equal impact on BP as genetic factors? *A person's BP levels are influenced by both their environment and genetic factors, which can affect their BP even in relaxed situations. Hypertension is a chronic condition with a significant genetic component, but lifestyle habits are equally crucial. Specifically, middle-aged individuals who lead sedentary lifestyles and are overweight are more likely to develop hypertension.*

4. What can a person with hypertension, or a lifestyle conditioned by stressful stimuli do to help lower their BP? *Reducing stress levels to compensate for the high BP experienced throughout the day and promote the body's recovery is essential. As a medical professional, I emphasize the importance of rest and disconnection, both physically through sufficient sleep, and mentally by employing techniques that stimulate the vagus nerve of the parasympathetic nervous system. Some examples of vagus nerve stimulation techniques to lower BP include practicing breathing exercises, taking cold water baths, engaging in laughter, singing or spending quality time and enjoying activities with friends among others.*

5. In your professional opinion, do you believe that the current treatments for hypertension are adequate? *Currently, there are many treatments available that rely on medication to reduce BP levels. However, as a medical*

professional, I believe that the focus of treatment should be on encouraging patients to make lifestyle changes and reduce stress in their daily routines. I understand that changing one's lifestyle can be difficult, and it's often easier for individuals to rely on taking a daily pill. But this brings up another issue we face today: since BP is typically measured at specific moments, it's challenging to determine which individuals are constantly experiencing high BP. As a result, it becomes difficult to verify the effectiveness of a specific treatment. It's just as harmful to suffer from hypertension as it is to receive an ineffective treatment that worsens the problem. I strongly emphasize the necessity of employing continuous monitoring technology that offers precise and real-time information on these parameters.

6. In the context of the body's adaptability to its environment, could it be possible for an individual to develop a tolerance to stress or other factors that could influence an elevation in BP, thereby mitigating their impact? *A person can manage or mitigate stress by practicing the activities mentioned earlier, but it's unlikely to fully eliminate its effects. Statistically, there is a higher incidence of stress-related diseases in large cities, indicating that busy lifestyles also have a negative impact on long-term health.*

5 DISCUSSION AD CONCLUSIONS

At the beginning of the project, the potential threat to the stability of the global healthcare system was emphasized. Although this challenge has been addressed using data regarding the national landscape, this problem affects most developed countries. After examining various data, it was concluded that the healthcare system faces a threat due to the increased life expectancy of the population, particularly among individuals over 65 years old who also suffer from more chronic diseases. These conditions lead to a considerable growth in healthcare expenses. To ensure the capacity of the national health system to cope with this situation, measures need to be taken to provide the necessary attention to the elder population in the near future.

Currently, there are numerous technologies related to telemedicine, both in use and under development, capable of providing great benefits not only for patients but also for healthcare professionals and the healthcare system in general. The use of teleconsultation before, during, and after the COVID-19 pandemic has demonstrated the positive impact of integrating telemedicine into the healthcare system and shifting the traditional focus of medical care, resulting in significant successes.

Throughout the study, numerous articles, blogs, reports, and scientific journals were reviewed. An attempt was made to universally define telemedicine and its various aspects, as well as to classify the devices used for patient telemonitoring and diagnostic, but it was concluded that there is no clear consensus. The diversity of approaches and the lack of a defined method to serve as a guide are overwhelming.

On the other hand, it is surprising how little consideration has been given to the technological advances that are revolutionizing all sectors with the use of Artificial Intelligence. Although modern devices employ algorithms to provide an interpretation of data obtained from different devices, it is regrettable that greater prominence is not given to this aspect.

The approach in telemonitoring often involves the autonomous functioning of an apparatus already used in in-person diagnosis, such as blood pressure monitors. The challenge of telemonitoring has been to ensure that these devices operate autonomously, obtaining various measurements over time, and storing the information to be later analyzed by the healthcare professional. On other occasions, telemetric measurement is not performed directly with the same technology as in face-to-face measurement, but rather indirect data is used that can be interpreted by a suitably trained AI algorithm. This would be the case, for example, with the estimation of blood pressure using images taken by a smartphone camera. However, there is greater potential for the use of the capabilities offered by telemonitoring, in conjunction with AI. This would involve obtaining, together with direct or indirect measurements of the diagnostic variable under study, other data related to the patient's general conditions, their environment, and their habits. With the integration of this tool into telemedicine devices, it would not only be possible to obtain information about the current state of the user but also a more comprehensive and, therefore, more useful view of their overall condition and foreseeable future evolution.

Nonetheless, it is important to note that all these benefits come with a series of limitations, such as ensuring the integrity and privacy of data and always safeguarding them. In addition, the integration of information from different devices, which can sometimes be of different types, is complex due to the diversity of existing formats, which hinders the unification of all this data.

In the current healthcare landscape, there is a significant challenge that, at the same time, provides a great opportunity for the digitization and improvement of the entire system. It is crucial to create and enforce worldwide policies that promote the use of telemedicine technologies and Artificial Intelligence in all aspects of public healthcare. This fact is crucial since numerous devices and systems have been developed so far for monitoring, diagnosis, and even disease prevention, both in remote and in-person settings. However, there is no clear approach or objective. It seems that each healthcare center incorporates the measures it deems appropriate in terms of telemedicine services, but there is no consensus on the steps to follow or the goals to achieve in order to achieve coherence in the future. Similarly, the same applies to developed technologies, where each device is created independently without a guiding principle defining what the ultimate goal of this whole process would be. Due to the coexistence of 17 local authorities managing the public health system in Spain, cooperation in the new paradigm of intensive utilization of remote medicine through technology, where delocalization is an issue, seems to be crucial.

It is paradoxical to reflect on how the first hospitals in history were created with the intention of providing care to the most disadvantaged, while those citizens with resources benefited from receiving the doctors in the comfort of their own homes. Advances in medical technology have made a 180-degree turn to this vision, and currently only in hospitals the best equipment and health services are available. This dynamic has prevailed for many years. However, with the advancement of technologies with potentially ominous implications, such as Artificial Intelligence, and events that have accelerated a global digital transformation, such as the COVID-19 pandemic, it seems that we are returning to square one in a way. The future of care is now in our own hands, in our own homes. Various telemedicine devices have proven to be highly efficient and improve patient prognosis. After so many centuries, it appears that we are entering an era where the future of medicine lies within our own homes.

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