WORKING PAPER SERIES

WEARABLES FOR AN INCLUSIVE UNIVERSAL HEALTHCARE SYSTEM IN MEXICO (Part I.)

The Competitive Intelligence Unit

Wearables for an Inclusive Universal Health System in Mexico

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ABSTRACT

Wearables are electronic devices that can be worn as clothing, accessories, or body implants. These devices can create, analyze, and report information regarding vital signs and send and receive these data through Internet. They may be used in a variety of alternatives to improve healthcare and wellness in the entire world: they can help to monitor symptoms, and disease diagnose, allowing more effective prevention, maintenance of health, and disease treatment.

Wearables are being used as a tool to increase the efficiency and reachability of healthcare systems in the entire world, being used primarily as gadgets that can continuously monitor, register and analyze various vital signs and parameters of physical activity. Wearables can complement and facilitate the mission of healthcare institutions as well as monitor patients' activities, allowing resources (human and material) to be used in more specialized tasks.

Wearables can also have many other benefits, like helping users with exercise routines, helping to create healthy eating habits and wellness in general. A variety of examples and experiments show the use of wearables is effective for preventing or controlling noncommunicable diseases (also called chronic diseases), which tend to be of long duration and the result of a combination of genetic, physiological, environmental and behavioral factors, as well as communicable diseases, such as COVID-19. An important challenge for the Mexican Health System and, particularly for the Mexican Institute of Social Security (IMSS for its acronym in Spanish), are the noncommunicable diseases (NCDs) that in 2018 caused more deaths than communicable diseases. Besides the increasing number of victims of the NCDs, their treatment causes a major financial impact to the public healthcare system as well as indirect, negative impacts to the economy due to the loss of human capital (deaths and loss of years of healthy life).

Wearables also have been explored to fight the recent COVID-19 pandemic. Some devices can enhance safety for people who have to be at a physical workplace, even with social distancing and physical isolation measures are in place.

A wearable-based strategy can promote physical activity and an efficient monitoring for NCDs. Adopting wearables to monitor patients' diseases and to generate a medical recorsd available for both the treating doctor and the patient could considerably reduce queuing times and medical consultations, allowing human and economic resources to be allocated to other important activities of the healthcare institutions.

Mexican regulation regarding the interoperability of electronic registration, health-related software and exchange of health information is an important step towards a wearables-based strategy. However, the fragmentation of the national healthcare system is a major challenge for its effective implementation.

The digital gap in Mexico, negatively impacts patients and public healthcare infrastructure, which could be addressed with the implementation of a reverse data billing strategy to close this gap and to ensure effective information exchange.

In this sense, to implement a wearables-based strategy for the Mexican Healthcare System, the following recommendations are made:

1. Include a gradual wearable-based strategy in the National Health Plan comprising relevant public and private actors and targeted groups of population considering risk management and cost-benefit analyses.
2. Focus on the use of wearables for preventing and controlling non-communicable diseases, the ones with the highest costs for the healthcare system.
3. Promote effective compliance to interoperability regulations in both the public and private systems.
4. Consider local and private previous experiences to improve existing interoperability regulations.
5. Review and update regulations aimed at ensuring the quality of health data and health-related software contained in wearables (e.g. promote the creation of wearables regulatory sandboxes).
6. Implement a reverse data billing strategy focused on the free provision of data to lower income households, and prepaid users.
7. Promote tax incentives to reduce wearables acquisition barriers and to promote associated software (applications) development.
8. Implement a smartphones-based system for the users and healthcare staff to visualize and analyze data considering the adoption patterns of these devices.

GLOSSARY OF TERMS AND DEFINITIONS

Ambulatory Blood Pressure Monitors (ABPM): Devices that allow blood pressure readings to be recorded over a 24-hour period, whether the patient is awake or asleep.

ChiquitIMSS and ChiquitIMSS junior: IMSS's prevention programs servicing kids in the range of seven to nine years and three to six years, respectively.

Comisión Federal para la Protección (COFEPRIS): Federal Commission for Protection against Sanitary Risk responsible for regulating health topics in Mexico, like food safety, pharmaceutical drugs, medical devices, organ transplants, and environmental protection.

Electrocardiogram (ECG): Test that records electrical activity through patches attached to the skin.

Food and Drug Administration (FDA): Federal agency of the United States Department of Health and Human Services responsible for protecting and promoting public health through control and supervision of food safety, pharmaceutical drugs, vaccines, and medical devices, among other products.

IMSS-Oportunidades: Public program that gives health services to people enrolled in Oportunidades Program.

Information and Communication Technologies (ICT): Refers to a broad set of communication technologies and devices such as wireless networks, smartphones, software, social networks and more.

Information and Communications Development Index (IDT): Index that sizes the development and usage of Information and Communication Technologies.

Information and Communications Development Index Mexico (IDTMex): Adaptation of the IDT to Mexico.

Instituto Mexicano del Seguro Social (IMSS): Healthcare system for workers of the private sector based on contributions by the firms and the workers themselves.

Instituto Nacional para la Salud y el Bienestar (INSABI): Healthcare system for people without social security.

Instituto del Seguridad y Servicios Sociales de los Trabajadores del Estados (ISSSTE): healthcare system for workers of the State.

Non-communicable disease (NCDs): is a disease that is not transmissible directly from one person to another.

Petróleos Mexicanos (PEMEX): refers to the healthcare sub-system for the workers of PEMEX (state-owned company).

PREVENIMSS: IMSS's fundamental strategy to prevent, detect and promote the timely diagnosis of cancer.

Remote Patient Monitoring (RPM): Use of digital technologies to collect medical data from individuals in any location and electronically transmit it to health care providers in another location.

Secretaría de la Defensa (SEDENA): refers to the healthcare sub-system for people at the army.

Secretaría de Marina (SEMAR): refers to the Healthcare sub-system for the navy.

The Organization for Economic Cooperation and Development (OECD): International organization that works to build better policies for better lives. Their goal is to shape policies that foster prosperity, equality, and well-being.

World Health Organization (WHO): Specialized agency of the United Nations responsible for international public health.

Wearable Blood Pressure Monitors (WBPM): Devices that expands and tightens to take blood pressure readings, in the same way as an upper arm oscillometer machines.

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1. INTRODUCTION

This Working Paper aims to describe the status of the current Mexican healthcare system, its link with technology and, more specifically, to analyze and highlight the benefits of having healthcare public policies which promote the adoption and use of wearables.

Wearables are electronic devices that can be worn as clothing, accessories, or body implants. These devices can continuously monitor, analyze, and report information regarding vital signs and sending and receiving these data through Internet. They may be used in a variety of alternatives to improve healthcare and wellness in the entire world: they can help to monitor symptoms and to diagnose illnesses, allowing a more ubiquitous prevention, maintenance of health and disease treatment.

It is regularly claimed that the National Healthcare System in Mexico needs large public investments to achieve universal coverage to service the growing population. This certainly may be true, if taken into consideration that total spending in the healthcare sector is equivalent to just 5.5% of the Gross Domestic Product (GDP), while this indicator goes from 9.8% to 12% in other OECD economies, like Canada, UK, Switzerland, Japan, and France, amongst others.[1]

However, the growing fiscal pressure resulting from the current public health and economic crisis, as well as the inefficient tax collection procedures, erodes public investment capacity. The country requires efficient spending strategies.

Mexico is in a transition phase where Non-Communicable Diseases (NCDs) are becoming more prevalent and cause more deaths every year. Mortality for acute respiratory infections or diarrheal diseases is declining while, diabetes, ischemic heart diseases and other NDCs are responsible for more deaths and require more resources for treatment year after year.

[1] OECD. "Health at a glance 2019, Health Statistics" 2019. Avalilable at: https://www.oecd-ilibrary.org/social-issues-migration-health/health-at-a-glance-2019_592ed0e4-en;jsessionid=67bfhqGJgYJ8NKIoal15fIQM.ip-10-240-5-113

That is why this document proposes an innovative strategy to promote the use of wearables for treating, monitoring, and preventing non-communicable diseases. This approach represents a cost-saving strategy but also an interoperability and connectivity challenge.

This document is structured as follows: the second section presents a literature review regarding the use of wearables in healthcare systems and successful experiments using these devices for healthcare purposes in the world. The third section describes some of the related costs to NCDs in the Mexican healthcare system along with the NCDs implications in the context of the Covid-19 pandemic. The fourth part analyzes the effectiveness of a wearable-based strategy to fight against NCDs by promoting physical activity and remote monitoring, i.e., prevention and control of NCDs with the use of wearables. The fifth part tackles the interoperability challenge, the relevance of connectivity gap in the discussion and other regulatory issues. The last part provides some general recommendations.

This document depicts the magnitude of NCDs problem for the healthcare system in Mexico and provides a general technology cost-effective strategy to address it.

2. WEARABLES IN HEALTHCARE SYSTEMS: A LITERATURE REVIEW

Nowadays, wearables are being used as a tool to increase the efficiency of healthcare systems in the entire world, primarily as gadgets that monitor, register and analyze various parameters of physical activity, as well as complements to healthcare Institutions, replacing traditional methods and devices. They also have many other benefits like helping users with exercise routines or creating healthy eating habits.

Wearables can help preventing diseases or alleviating them, while having the advantage of been available at all time, no matter the situation the user is dealing with. The use of these devices turns out to be cost efficient for tracking or combating diseases and replacing hospital visits, for example. In short, these devices can complement and facilitate the mission of healthcare institutions as well as monitor patients' activities, allowing human and material resources to be allocated in more specialized tasks.

I. *POTENTIAL USE OF WEARABLES IN HEALTHCARE*

Wearables are electronic devices that can be worn as clothing, accessories, or body implants. These devices can monitor, create, analyze, and report information regarding vital signs and sending and receiving these data through Internet. Accessories that take advantage of the actual technology include smart watches, wrist bands, jewelry, and clothing, among others.

Wrist bands and smart watches use sensors to track and measure physical activity for example, heart rate, sleep patterns or weight control. By doing so, the wrist bands show the wearer the data obtained and, when connected to other applications, they provide recommendations on how to improve exercises and eating habits, incentivizing physical activity.

The importance of promoting physical activity lies in its impact on preventing NCDs such as diabetes, heart diseases, colon cancer, obesity, and hypertension among others, as stated by the World Health Organization (WHO). [2]

[2] World Health Organization. "Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World". Available at: http://apps.who.int/iris/bitstream/handle/10665/272722/9789241514187-eng.pdf

Another wearable used in healthcare providing great benefits, are the biosensors in auto-adhesive patches that continuously measure vital signs like heart and respiratory rate, skin temperature, posture, and physical activity. This type of technology is relevant for people with chronic conditions that require continuous monitoring, as it becomes easier to gather their medical data, register patterns, and show it at any time.

Clinically validated smart watches are already in the market that allow users to track their blood pressure in about 30 seconds, to observe sleep characteristics, such as patterns, quality, and duration, and to track steps, distance and calories burned.

Smartwatches have an ability to contact emergency services if a sudden fall is detected. This automated feature can also share the exact location of the affected person who is otherwise unable to do so, becoming a crucial service for saving lives.

Additionally, wearables can reduce the costs of healthcare, by reducing hospital trips and providing preliminary health diagnosis without generating extra expenses. These devices can assist doctors or surgeons, allowing them to access real-time data to follow up or analyze the severity of each case, directly impacting on clinical decision-making.

Wearables can improve hospital's efficiency, by using portable sensors and similar devices to facilitate a continuous monitoring of risks that endanger patient lives and health. These devices enable detection of heart and breathing rates, body temperature, blood oxygen saturation, position, activity, posture, external temperature, presence of toxic gases, and heat flux passing through garments.[3]

Tracking heart rate, pressure and other health parameters through wearables may require mobile applications as a platform that can be used to connect the patients with their doctors, allowing healthcare staff to track and to easily check data from their patients, ensuring any treatment is working as intended or preventing disease progress.

[3] D. Curone et al., "Smart Garments for Emergency Operators: The ProeTEX Project," in IEEE Transactions on Information Technology in Biomedicine, vol. 14, no. 3, pp. 694-701, May 2010, doi: 10.1109/TITB.2010.2045003. Available at: https://ieeexplore.ieee.org/document/5443746

In a moment when society is becoming more aware of the importance of mental health, wearables can play a central role by providing healthcare institutions with quantifying information to detect disorders such as depression which affects 300 million people around the world according to WHO[4]. The University of California, Los Angeles (UCLA) is conducting a research to explore with the help of smart watches how sleep patterns, physical activity, and heart rate correlates with depression. It is noteworthy that UCLA designed this research so all participation aspects are executed remotely.[5]

There are challenges to the growth of wearable health technology that are likely to hinder widespread adoption across health systems, mainly those related to interoperability and data collection issues. Some companies are addressing interoperability issues by linking hospitals' electronic health records systems to third party applications, while other solutions are working simplifying data collection from devices and outputting easily understandable results.[6]

II. *WEARABLES APPLICATIONS FOR HEALTHCARE*

In this section we review a range of studies to show the potential impact on healthcare services when taking advantage of wearables technology capabilities. They are mainly focused on patient management, prevention of diseases, and disease management.[7]

The appendix section provides more studies for further reference.

a. PATIENT MANAGEMENT

Wearable Blood Pressure Monitors (WBPM) have proven to be a better alternative to Ambulatory Blood Pressure Monitors (ABPM), as patients find it more comfortable, less intrusive, and less burdensome. Additionally, WBPMs facilitate multiple readings in different conditions,

[4]WHO. "Depresión", 2020. Available at: https://www.who.int/es/news-room/fact-sheets/detail/depression
[5]UCLA. "UCLA launches major mental health study to discover insights about depression", 2020. Available at: https://newsroom.ucla.edu/releases/ucla-launches-major-mental-health-study-to-discover-insights-about-depression

[6]Dinh-Le C, Chuang R, Chokshi S, Mann D. "Wearable Health Technology and Electronic Health Record Integration: Scoping Review and Future Directions". JMIR Mhealth Uhealth 2019;7(9):e12861. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6746089/

[7]Op. Cit. Wu, M. & Luo, J.

over multiple days, increasing reliability of blood pressure measurements, as well as they improve the reliability of hypertension diagnosis and facilitate its treatment.[8]

Some applications enhance smartwatches ability to monitor blood pressure by uploading data to wireless monitors connected via Bluetooth or Wi-Fi. These monitors stand out by their accuracy to measure blood pressure, using advanced algorithms and higher proficiency on eliminating interference from movement; they also provide immediate feedback on the device and readings history through the application, allowing patients to share their data with healthcare professionals. This also applies for body temperature, where apps are already available for smartwatches to register it.

It has been proven that the use of smartwatches, and proper incentives for their acquisition, physical activity is promoted [9]. Considering this, wearables represent an attractive alternative to traditional policies encouraging physical activity such as installing signage in public space, separating parking lots from buildings by green spaces, or developing videogames requiring activity.[10]

b. Disease prevention and Injury Prevention

There have been numerous cases where smartwatches have saved lives through fall-detection systems. One of those cases happened in Arizona where, in April 2020, the Police Department Center received a 911 call from a computer-enhanced voice indicating that a smartwatch user had fallen and was not responding. The voice provided near-exact coordinates of the man's location where patrol officers were able to find him.

An easy-to-use smartwatch-based solution for medication adherence, emergency calls and live GPS tracking for seniors enables physicians and companies to offer Remote Patient

[8]Kairo, Kauzomi et al. "The first study comparing a wearable watch-type blood pressure monitor with a conventional ambulatory blood pressure monitor on in-office and out-of-office settings". Available at: https://onlinelibrary.wiley.com/doi/full/10.1111/jch.13799

[10] Sallis, James F, Adrian Bauman, and Michael Pratt. "Environmental and policy interventions to promote physical activity." American journal of preventive medicine 15.4 (1998): 379-397.

Monitoring (RPM) services through their platforms. This results in improved patient quality of life and better accessibility for their users.[11]

Wearable medical devices that conduct electrocardiograms (ECGs) have been approved by the U.S. Food and Drug Administration (FDA). Some of these devices, which record, store, transfer, and display single-channel ECG rhythms, are prescription-only devices intended for healthcare professionals, patients with heart conditions, and health conscious individuals.[12]

The development of these devices goes in hand with ECG apps (software-only health applications). Available for some smartwatches, this type of apps allows users to have more accessible means to record ECGs, in a constant manner, with the possibility of being reviewed by medical professionals to determine if data is related to cardiac rhythm abnormalities.[13] This has been very valuable for patients who have been forced to stay at home and reduce their visits to health service providers during confinement due to the Covid-19 pandemic.

c. Disease Management

For cancer patients, studies evaluated the acceptability and effectiveness of a physical activity monitor for endometrial cancer survivors. Results exhibit that wearables were well accepted, as well as two intervention outcomes. First, wearables helped cancer patients to track their status, allowing them to observe their condition, reducing the frequency of visits to hospitals and, at the same time, reducing commuting costs (e.g. to see their doctor). Second, the data obtained helped doctors to check for similarities between patients while facilitating patients' observation.

Wearable trackers have the potential to improve hypertension control and medication adherence through ambulatory blood pressure measuring and medication reminder alerts.

[11] MedCity News. "WatchRx unveils remote patient monitoring platform and services". Available at: https://medcitynews.com/2020/03/watchrx-unveils-remote-patient-monitoring-platform-and-services/?rf=1

[12] HCPLive. "FDA Approves ECG Device, Verily Study Watch". Available at: https://www.mdmag.com/medical-news/fda-approves-ecg-device-verily-study-watch

[13] U.S. Food and Drug Administration. "De Novo Classification Request For ECG App". Available at: https://www.accessdata.fda.gov/cdrh_docs/reviews/DEN180044.pdf

In a similar path, it was found that patients using a wearable simulating the functionality of an artificial pancreas improved adjustment of patient glucose values and less overall insulin infusion.[14]

It is also possible to take advantage of data collected from wearables tracking physical activity to detect influenza outbreaks. Infections that affect heart rates and routines patterns suggest the presence of influenza or other seasonal respiratory infections.[15] These devices are also used for brain and spinal cord injuries, Parkinson's disease, autism, and depression, among others. Therefore, their relevance is increasing as technology does.

III. *WEARABLES DURING COVID-19 PANDEMIC*

Wearables have been also explored to fight the COVID-19 pandemic. The King's College London launched a mobile app which allows research regarding the use of wearable devices and smartphones for digital detection of COVID-19. In this investigation, participants use wearables such as smart bands to monitor information about their heart rate, and physical activity. Data will be analyzed when a participant reports feeling ill or tests positive for COVID-19 and will be compared with data during healthy periods, this will allow researchers to develop a digital test to detect coronavirus.

Smartwatches and specialized applications tracking users' heart rate during sleep can be used to understand COVID-19 infection process. This type of infection impacts heart rate due to blood cell inflammation.[16]

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[14] Dudde, Ralf & Vering, Thomas & Piechotta, Gundula & Hintsche, Rainer. "Computer-Aided Continuous Drug Infusion: Setup and Test of a Mobile Closed-Loop System for the Continuous Automated Infusion of Insulin", 2016, IEEE transactions on information technology in biomedicine: a publication of the IEEE Engineering in Medicine and Biology Society. 10. 395-402. 10.1109/TITB.2006.864477. In a similar line of research and experimentation, see also Lee, Hyunjae & Song, Changyeong & Hong, Yong & Kim, Min & Cho, Hye Rim & Kang, Taegyu & Shin, Kwangsoo & Choi, Seung & Hyeon, Taeghwan & Kim, Dae-Hyeong. "Wearable/disposable sweat-based glucose monitoring device with multistage transdermal drug delivery module", 2017. Science Advances. 3. e1601314. 10.1126/sciadv.1601314.

[15] Radin, Jennifer M et al. "Harnessing wearable device data to improve state-level real-time surveillance of influenza-like illness in the USA: a population-based study". The Lancet Digital Health, Volume 2, Issue 2, e85 - e93

[16] Parikh P. "Apple Watch Users Can Now Monitor How Bodies React To Coronavirus". Masahable. Available at: https://in.mashable.com/tech/12466/apple-watch-users-can-monitor-how-bodies-react-to-coronavirus-flu

As mentioned, there are electrocardiogram applications for smartwatches that have been cleared by the FDA for remote patient visits during public health emergencies, allowing clinicians to use it as a remote monitoring device. As such, the smartwatches now can serve as a substitute for in-clinic diagnostic testing. Patients can export their PDF summaries to their medical record and information gathered is stored encrypted on the patients' device, protecting user privacy due the fact that only the users can share data.[17] Furthermore, users now have a handwashing detection feature, using the motion sensors, microphone and on-device machine learning to automatically detect handwashing motions and sounds. If the user initiates a 20-second countdown timer and finishes early, they will be prompted to keep washing, reducing the probability of infections.[18]

Researchers at Duke University are exploring how data collected by wearables may help determine whether its users have COVID-19. The study, called *CovIdentify*, is recruiting participants through a website that let them register and analyze wearers' physical conditions, such as sleep schedule, oxygen levels, activity levels, and heart rate, among many others. In a previous work, they had already shown that biometric data collected from wearables can indicate if someone is susceptible to various health issues, like diabetes or cardiovascular disease, or if infections have been contracted.[19]

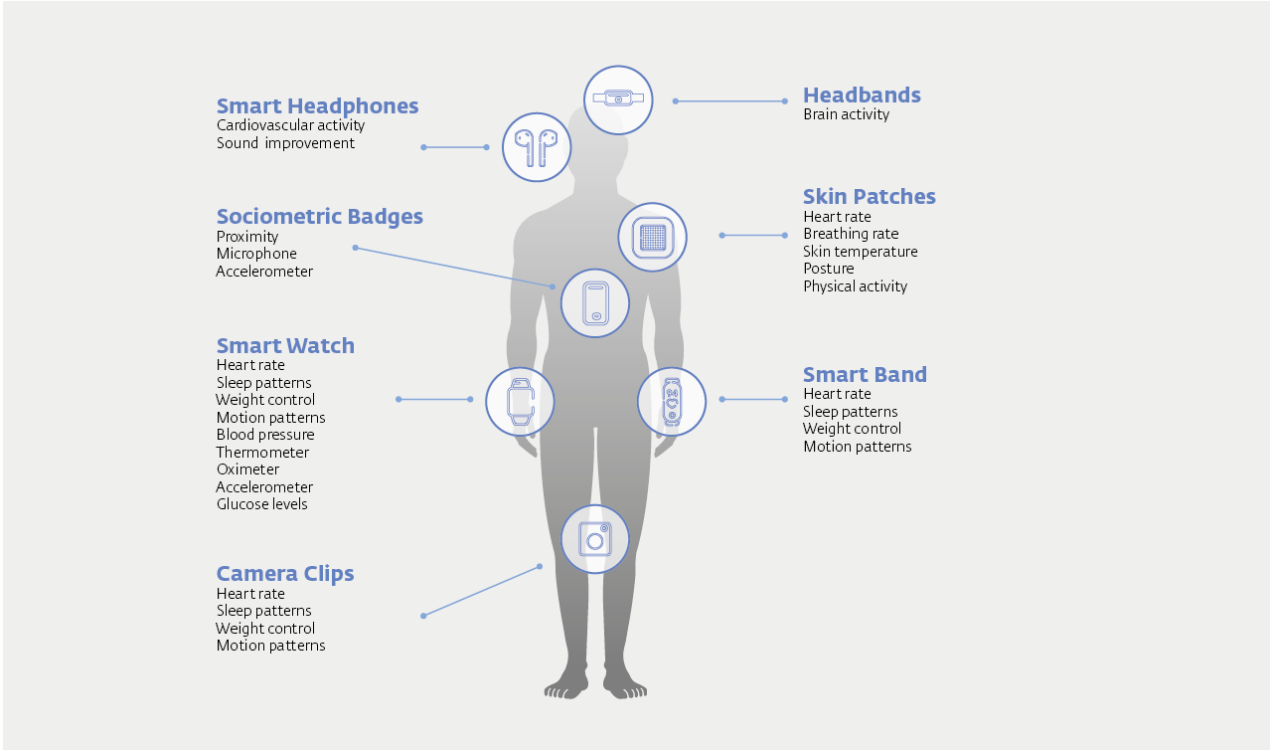
Wearables are already helping the prevention and understanding of infectious diseases like COVID-19, while helping the treatment of users that already have a disease, as they track and analyze measures like pulse, blood oxygen, blood pressure and heart rate. The overall benefits and uses of wearables in health is illustrated in Figure 1.

[17] Becker's Hospital Review. "FDA clears Apple Watch ECG for remote patient visits during pandemic: 6 things to know". Available at: https://www.beckershospitalreview.com/cardiology/fda-clears-apple-watch-ecg-for-remote-patient-visits-during-pandemic-5-things-to-know.html

[18] 9to5Mac. "Apple Watch handwashing detection was years in development; may be more to come". Available at: https://9to5mac.com/2020/06/29/apple-watch-handwashing/

[19] Pratt School of Engineering. "'CovIdentify' Pits Smartphones and Wearable Tech Against the Coronavirus". Duke University. Available at: https://pratt.duke.edu/about/news/covidentify-pits-smartphones-and-wearable-tech-against-coronavirus

Fig. 1 Use of wearables in health



Source: The CIU, 2020.

3. NON-COMMUNICABLE DISEASES (NCDS) COST IN MEXICO

I. *OVERVIEW OF HEALTHCARE SYSTEM IN MEXICO*

The State is responsible for guaranteeing the universal healthcare access according to the Mexican Constitution and the General Health Act. However, 3.1 million inhabitants of isolated localities (2.5% total population) had no access to these services in 2018. [20]

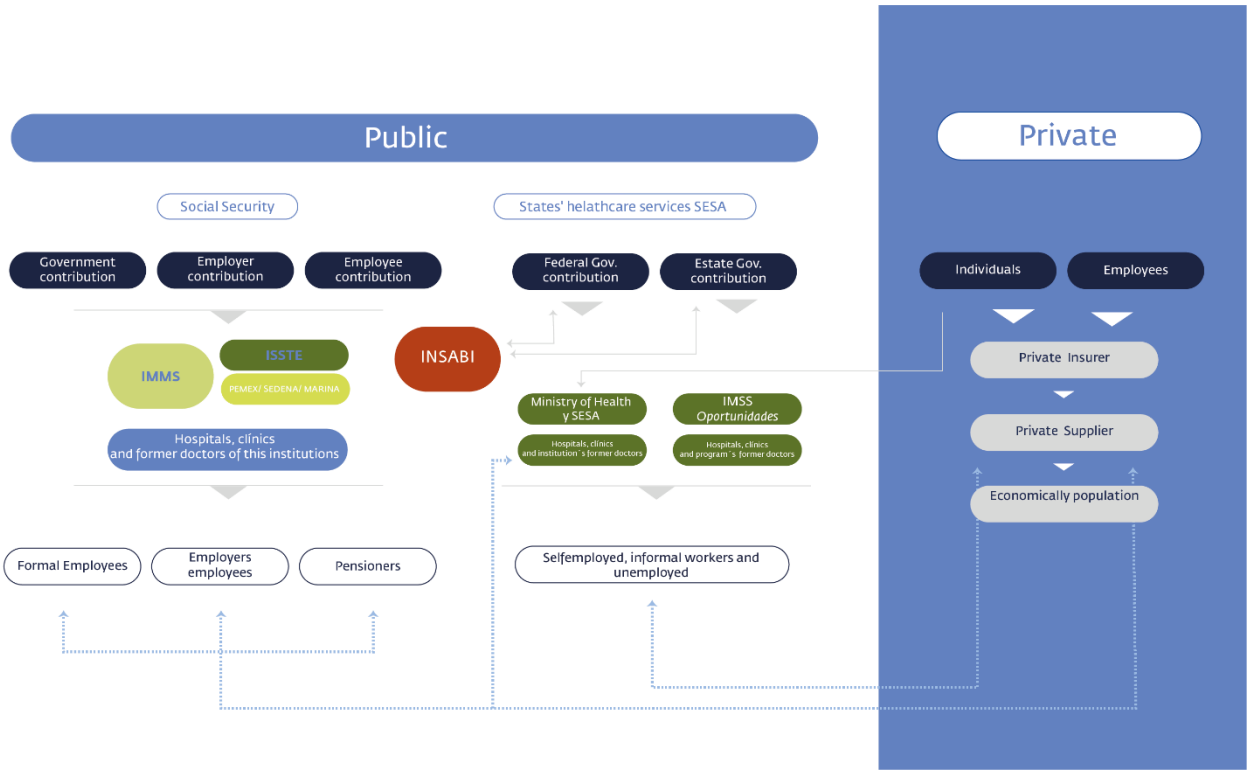
Mexican Constitution establishes that healthcare must be coordinated at all levels of government (by the Federation, the states and the municipalities); while the General Health Act stablishes that not only federal authorities (the President, the General Health Council and the Health Ministry) are health authorities but also the states.

Mexico's healthcare system is split into private and public healthcare subsystems. The public sector includes institutions providing social security, such as Instituto Mexicano del Seguro Social (IMSS), for workers of the private sector based on contributions of the enterprises and the workers - and accounts for more than 30% of people with healthcare assurance in the country-[21], Instituto del Seguridad y Servicios Sociales de los Trabajadores del Estados (ISSSTE), Petróleos Mexicanos (PEMEX), Secretaría de la Defensa (SEDENA), and Secretaría de Marina (SEMAR), as well as programs servicing people with no social security (INSABI, local healthcare services, IMSS-Oportunidades). On the other hand, the private sector includes private hospitals, medical clinics and insurance companies. The Figure 2 (Gomez-Dántes et al. ,2011) displays the structure of the Mexican health system.

[20] CONEVAL. "Principales Retos en el Ejercicio del Derecho a la Salud". Available at: https://www.coneval.org.mx/Evaluacion/IEPSM/Documents/Derechos_Sociales/Dosieres_Derechos_Sociales/Retos_Derecho_Salud.pdf

[21] Instituto Mexicano para Competitividad (IMCO). "Sistema Universal de Salud Retos de Cobertura y Financiamiento Vía CIAP". Disponible en: https://imco.org.mx/sistema-universal-salud-retos-cobertura-financiamiento-via-ciep/

Fig. 2 Structure of the Mexican health system



Source: Updated from Gómez- Dantés et al. "Sistema de salud de México", 2011.

Regarding the healthcare challenges -before Covid-19 pandemic- faced by the system and as stated in the introduction, Mexico is in an epidemiological transition phase where NCDs were more prevalent and caused more deaths in 2018 than communicable diseases like acute respiratory infections or diarrheal diseases. In 1976, communicable diseases brought more deaths than NCDs[22], this transition represents a resource reallocation challenge to deal with increasing prevention and treatment costs related to diabetes, ischemic heart diseases and other NCDs.

The universal access to health services in Mexico is a non-achieved mandate; the fragmentation of the system generates a lack of coordination among the different insurance schemes[23] and high costs related to NCDs are major challenges that generate further

[22] *Ibid.*

[23] IMSS. "2018-2019 Report to the Federal Executive and to the Congress of the Union on the Financial and Risks Status of the Mexican Institute of Social Security", 2019. Mexico.

inefficiencies and inequalities in the provision of services that require innovative strategies to enhance full coverage.

II. *NCDs' Treatment Costs*

As mentioned, an important challenge for IMSS and the Mexican healthcare system as a whole are the NCDs (e.g. diabetes mellitus, ischemic heart disease, brain-vascular diseases). Besides the increasing number of victims, their treatment causes a major financial impact to the public healthcare system. According with the 2018-2019 Financial and Risk Status Report of IMSS, six NCDs with higher financial impact among their beneficiaries are: i) arterial hypertension arterial; ii) diabetes mellitus; iii) cervical cancer; iv) breast cancer; v) prostate cancer, and vi) chronic kidney failure.[24]

Medical expenses incurred in 2018: six diseases of high economic impact

Disease	Number of treated patients	Spending (millions of 2019 Mexican pesos)		
		Outpatient	Hospital	Total
Arterial hypertension	4,760,161	$ 18,397	$ 4,171	$ 22,568
Diabetes mellitus	3,016,588	$ 34,369	$ 2,744	$ 37,113
Terminal chronic kidney failure	71,086	$ 10,387	$ 1,376	$ 11,763
Breast cancer	56,254	$ 2,067	$ 795	$ 2,862
Cervical cancer	19,313	$ 353	$ 242	$ 595
Prostate cancer	23,944	$ 666	$ 220	$ 886
Total	7,947,346	$ 66,239	$ 9,548	$ 75,787

Source: 2018-2019 Financial and Risk Status Report of the IMSS

7.9 million beneficiaries of the IMSS healthcare services are treated for those NCDs, which is 14% of people at its Family Medicine Units and 6.3% of the total estimated population in 2018.

Not only is the financial status of public healthcare institutions in Mexico threatened, the insufficient coverage of the healthcare system jeopardizes the financial stability of households.

[24] *Ibid.*

According to the Annual Health report of the Organization for Economic Cooperation and Development (OECD), in 2019, Mexico was the second member country with the highest proportion of healthcare costs paid directly by households: it was estimated that 5.5% of households experience catastrophic health spending, with poor households being the most affected.[25] Besides:

> Studies in the Region have found that 78% of what is paid for medication is not planned for in the family budget and is out of the reach of vulnerable population groups, all of which [...] exacerbates poverty and increases health inequalities. [26]

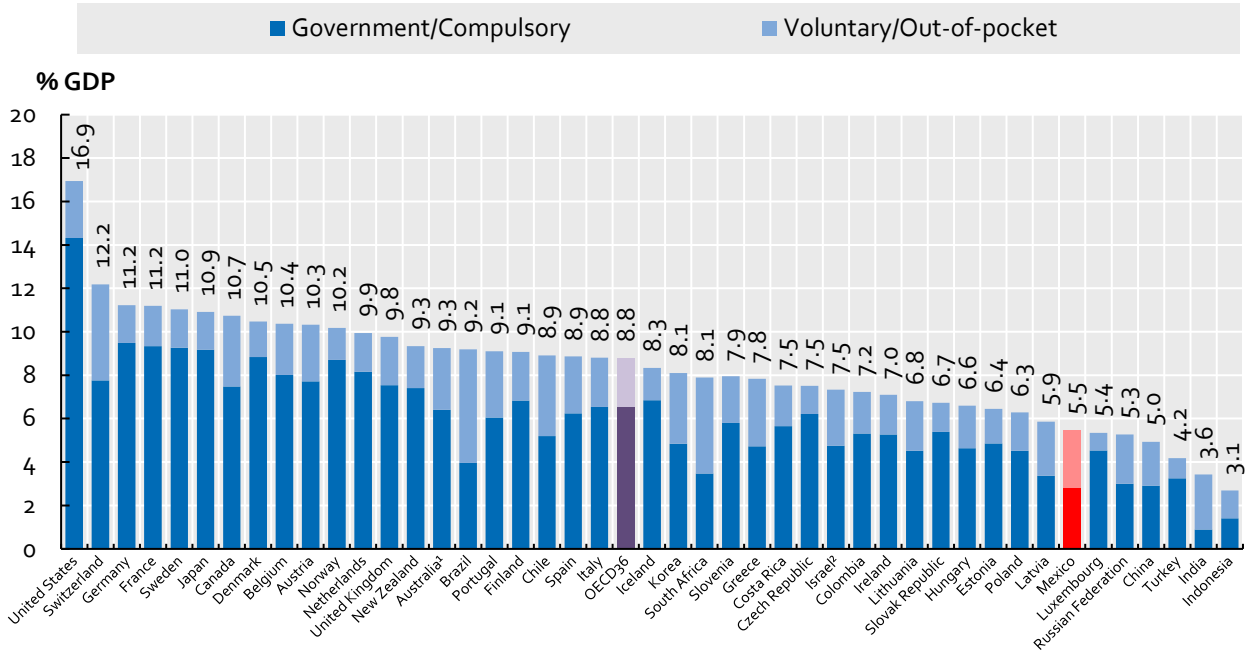
The coverage of a basic set of healthcare services in Mexico is 89.3%, the lowest among OECD countries which illustrates the poor distribution of healthcare resources and rights among people[27]. Additionally, in comparison with the other country members of the OECD, Mexico is one of the countries that less expends in health as a share of its GDP. In Figure 3 (OECD,2019) the expenditure of Mexico (in red) is smaller than the average (in purple) and even smaller than countries of the same region as Costa Rica or Colombia.

[25] OECD. "Health at a Glance 2019". Mexico, 2019. Available at: http://www.oecd.org/mexico/health-at-a-glance-mexico-ES.pdf

[26] WHO. "Report. High-Level Regional consultation of the Americas Against NCDs and Obesity". P.19.

[27] OECD. "Health at a Glance 2019". Mexico, 2019. Available at: http://www.oecd.org/mexico/health-at-a-glance-mexico-ES.pdf

Fig. 3 Health expenditure as a share of GDP, 2018 (or nearest year)



Note: Expenditure excludes investments, unless otherwise stated.
1. Australian expenditure estimates exclude all expenditure for residential aged care facilities in welfare (social) services.
2. Includes investments
Source: OECD Health Statistics 2019, WHO Global Health Expenditure Database

III. *MORTALITY AND LOSS OF HEALTHY YEARS*

Having a proportion of people suffering NCDs can generate other public costs, not only due to the cost of public treatment, but to mortality and loss of healthy years. According with the Mexican NCDs Observatory, in 2016 and 2017, NCDs related deaths were on the top of the chart. Cardiovascular diseases, diabetes and malignant tumors were the three leading mortality causes. In 2017, the NCDs related deaths amounted for 141, 619 while in the previous year, deaths caused by those diseases were 136,342. [28]

NCDs related deaths tend to be associated with elderly people, nevertheless these deaths also have an important negative impact on population's more productive years. NCDs such as diabetes, ischemic heart diseases, and malignant tumors remain as the leading death causes

[28] OMENT. "Mortalidad por enfermedades no transmisibles en México", 2019. Available at: http://oment.salud.gob.mx/aumentan-en-mexico-muertes-relacionadas-con-enfermedades-no-transmisibles/

among people between 45 and 65 years. As for women in the 35-44 years group, malignant tumors, diabetes, and heart diseases are the three leading death causes, while heart diseases, diabetes and malignant tumors are the 4th, 5th, and 6th death causes among men in this age group. Regarding people between 25 and 34 years, malignant tumors, hearth diseases and diabetes were ranked as the 3rd, 4th, and 8th death causes.[29]

On the other hand, and according with 2015 available data of beneficiaries of IMSS, NCDs generated a loss of 170 healthy years per 1,000 IMSS users, this is a considerable loss of healthy years if we consider that for all diseases treated by IMSS, the loss of heathy years is equivalent to 208 years.[30] In contrast, WHO revealed that in 2016 in the region of the Americas, which is formed by 33 countries (including Mexico, Brazil, Colombia, Canada and the United States), the years of life lost due to NCDs was close to 126 per 1,000 inhabitants.[31]

In 2015, the Mexican Institute for Competitiveness (IMCO) estimated that the social cost of type 2 diabetes mellitus, a disease highly correlated with obesity, amounted to more than 85 billion pesos. [32] Just to set a reference, this amount is almost three times the investment cost of the expansion of the Veracruz Port. [33]

Worryingly, people who "develop diseases related to overweight and obesity, once these diseases manifest themselves, can be sick for roughly 15 years [...] The estimated cost in Mexico is $3.5 billion dollars per year".[34] This information suggests that the timeframe of NCDs represent an important factor to be considered on Mexican public system and households costs.

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[29] WHO. "Enfermedades no Transmisibles", 2018. Available at: https://www.who.int/es/news-room/fact-sheets/detail/noncommunicable-diseases

[30] Op. Cit. IMSS, p.123.

[31] Global Health Estimates 2016: Disease burden by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva, World Health Organization; 2018.

[32] IMCO. "Kilos de más, pesos de menos: los costos de la obesidad en México", 2015. Available at:https://imco.org.mx/kilos-de-mas-pesos-de-menos-obesidad-en-mexico/

[33] Milenio. "Inauguran el Nuevo Puerto de Veracruz",2019. Available at: https://www.milenio.com/negocios/inauguran-el-nuevo-puerto-de-veracruz

[34] World Health Organization, et al. "High-Level Regional Consultation of the Americas against NCD's and Obesity". Available at: https://www.paho.org/hq/dmdocuments/2011/Reporte-Mexico.pdf

Therefore, a complete view of the impact of the NCDs on the economy, establish the importance to consider two additional factors:

1. mortality and loss of healthy years that limit the availability of human capital and increase work absenteeism linked to treatment, and
2. the duration which multiplies the cost of the disease.

This enormous burden of the NCDs to the public healthcare system and household represents a serious calling for strategies aimed at preventing and attending such diseases with innovative methods.

As explained in the first part of this document, wearables can have a role to become the technology-based tool that can help alleviate costs.

IV. *COVID-19 IMPACT IN MEXICO*

The meta-analysis performed by Yang J, Zheng Y, Gou X, et al. reported clinical research suggesting that comorbidities on COVID-19 patients may represent a "risk factor for adverse outcomes" in the treatment of these diseases. The document shows the results of a study on a group of 41 confirmed cases, where 32% had comorbidities, while in other study practiced to a group of 138 cases, 46.4% showed comorbidities.[35]

Statistics from the Mexican health authority show that most of these comorbidities are NCDs. By the end of June 2020 20.1% of the confirmed cases suffered hypertension, 19.6% had obesity and 16.4%, diabetes.[36]

This information suggests that COVID-19 impact on Mexico would have been less (in terms of the number of cases and the number of deaths) if the prevalence of NDCs would have been smaller.

[35] Yang J, Zheng Y, Gou X, et al. Prevalence of comorbidities in the novel Wuhan coronavirus (COVID-19) infection: a systematic review and meta-analysis. International Journal of Infectious Diseases 2020; 94: 91-95

[36] Information updated on June 29, 2020 and available at: https://coronavirus.gob.mx/datos/

Another impact of the pandemic, stated by the World Health Organization, is that patients with NCDs around the world are not receiving proper medicine, treatment or specialized healthcare staff since a lot of resources have been reallocated towards COVID-19 treatment.[37] This situation requires innovative responses, and telemedicine may represent an option to provide follow-up to patients suffering diabetes, hypertension or other diseases of this type.

Wearables may represent an innovative tool since there are solutions capable of providing physical activity reminders for confined people, collect useful data for NCDs monitoring and complications assessment.

The pandemic puts NCDs prevalence in the spotlight by showing how COVID-19 affect patients in the presence of such comorbidities. It also represents an opportunity to fight against NCDs in an efficient manner since pandemic requires an effective allocation of healthcare resources.

[37] WHO. "COVID-19 disrupting services to treat non-communicable diseases, WHO survey finds", 2020. Available at: https://news.un.org/en/story/2020/06/1065172

4. Conclusions and General Recommendations

This document recommends the implementation of a wearables-based strategy in the healthcare system. The features and applications developed for wearables in the healthcare sector make them an ideal complementary tool in the control and prevention of NCDs, which are the diseases with the highest incidence and costs for the Mexican healthcare system.

Wearables promote physical activity and an efficient monitoring for NCDs and to fight against Covid-19 pandemic and facilitates the mission of healthcare institutions as well as allows resources (human and material) to be allocated in more specialized tasks.

Mexican regulation regarding the interoperability of electronic registration and exchange of health information is an important step towards a wearables-based strategy. However, the fragmentation of the national healthcare system, the lack of regulation enforcement and technical specifications represent a major challenge for its effective implementation.

Connectivity plays a fundamental role so that information collected from wearables can reach healthcare staff and patients.

In this sense, to implement a wearables-based strategy for the Mexican Healthcare System, the following recommendations are made:

1) Include a gradual wearable-based strategy in the National Health Plan comprising relevant public and private actors and targeted groups of population considering risk management and cost-benefit analyses.

2) Focus on the use of wearables for preventing and controlling non-communicable diseases, the ones with the highest costs for the healthcare system.

3) Promote effective compliance to interoperability regulations in both the public and private systems.

4) Consider local and private previous experiences to improve existing interoperability regulations.

5) Review and update regulations aimed at ensuring the quality of health data and approval devices such as wearables (promote the creation of wearables regulatory sandboxes).

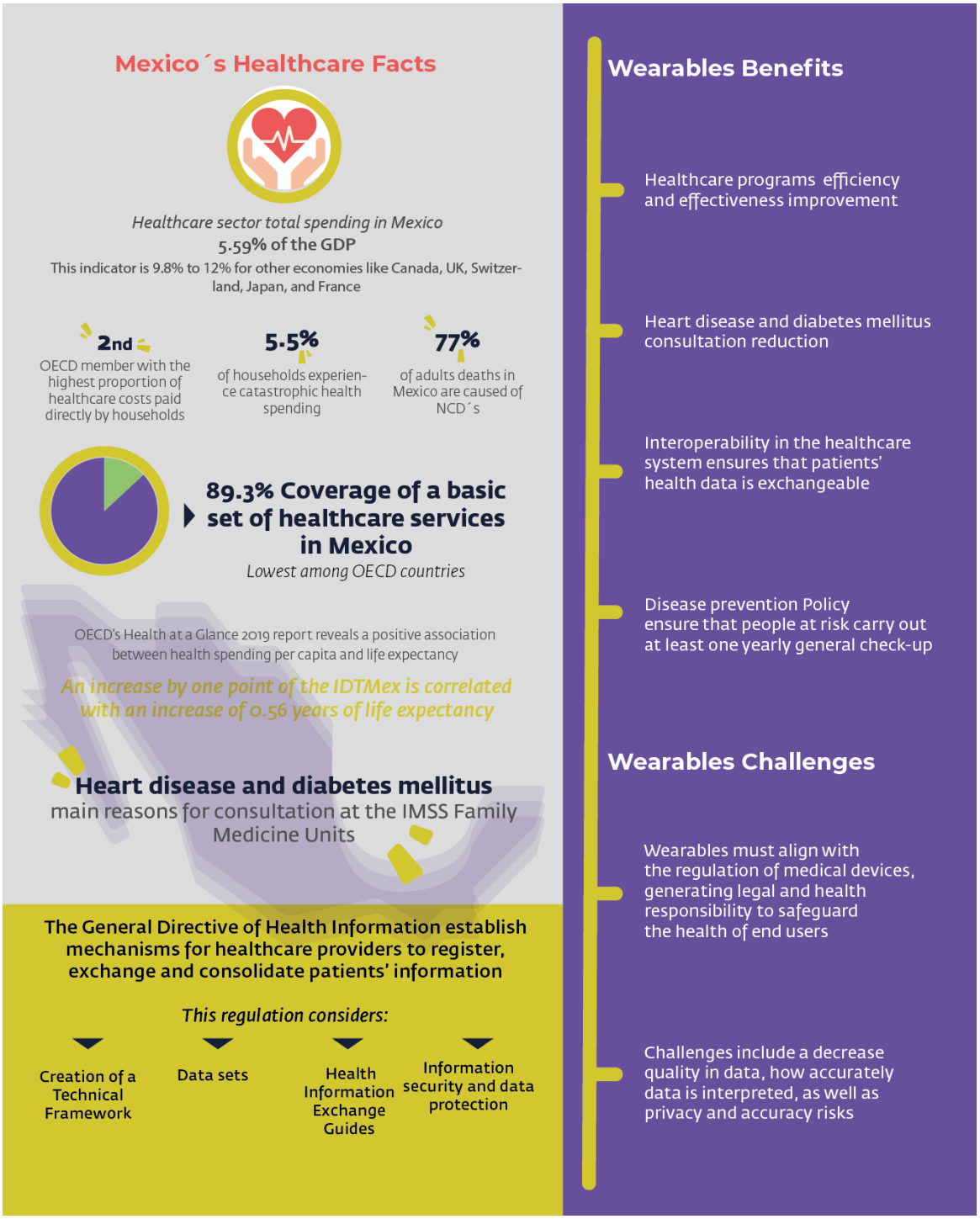
6) Implement a reverse data billing strategy focused on the free provision of data to lower income households, and prepaid users turn out to be a good guide.

7) Promote tax incentives to reduce wearables acquisition financial barriers and to promote the adoption of mobile devices and associated software (applications) development.

8) Implement a smartphone-based system for the users and healthcare staff to visualize and analyze data considering the adoption patterns of these devices.

The Mexican healthcare system is facing important challenges to guarantee universal coverage. The implementation of a wearable-based solution may represent an opportunity to alleviate the financial pressure and increase the reach of the system as mandated by the Constitution.

Fig 5. Mexico´s Healthcare



Source: The CIU, 2020.

5. APPENDIX: WEARABLES IN HEALTHCARE SYSTEM, A LITERATURE REVIEW

Focusing on Patient Management, Chen et al. showed that wearables can be used to monitor heat stroke risk, alerting users, and therefore preventing harm. [38] Nguyen, N. H. et al. found that wearable technique programs have the potential to provide effective, intensive, home-based rehabilitation, which represent an opportunity to reduce hospitalization costs. [39] By doing this, patients will be safer if they use these devices as a method to track their health.

Physical activity lower risks of various major non-communicable diseases, while improving wellbeing and mental health at the same time. In this regard, Hafner M. et al. prove that the use of smartwatches, and proper incentives for its acquisition, promote physical activity, reducing inactivity and sedentary lifestyles. [40] Furthermore, technology innovation keeps adding more tools to these devices, for example, some smartwatches added blood oxygen measurement capabilities with an integrated health sensor, able to measure it in only 15 seconds, while periodically storing user information in the health app.[41]

Frank, Jacobs, and McLoone used wearable device-based systems with vibration capabilities to remind students of taking breaks after long sessions of sitting, to change (and investigate) students' posture. [42]

In a similar way, and with an effort to reduce the frequency of patient visits to medical centers, Choo, Dettman, and Dowell proposed a rehabilitation system that combines wearables devices

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[38] Chen, Sheng-Tao & Lin, Shin-Sung & Lan, Chein-Wu & Hsu, Hao-Yen. "Design and Development of a Wearable Device for Heat Stroke Detection", 2017. Sensors (Basel, Switzerland). 18. 10.3390/s18010017. Available at: https://www.researchgate.net/publication/322024732_Design_and_Development_of_a_Wearable_Device_for_Heat_Stroke_Detection

[39] Nguyen NH, Hadgraft NT, Moore MM, et al. "A qualitative evaluation of breast cancer survivors' acceptance of and preferences for consumer wearable technology activity trackers". Support Care Cancer. 2017;25(11):3375-3384. doi:10.1007/s00520-017-3756-y. Available at: https://www.ncbi.nlm.nih.gov/pubmed/28540402

[40] Hafner M., Pollard J., and van Stolk Christian. "Incentives and physical activity" Rand Corporation 2018. Available at: https://www.rand.org/pubs/research_reports/RR2870.html

[41] CNET. "Apple Watch Series 6 now measures blood oxygen, but it's not a medical device". Available at: https://www.cnet.com/news/apple-watch-series-6-now-measures-blood-oxygen-but-its-not-a-medical-device/

[42] Frank HA, Jacobs K, McLoone H. "The effect of a wearable device prompting high school students aged 17-18 years to break up periods of prolonged sitting in class". Work. 2017;56(3):475-482. doi:10.3233/WOR-172513. Available at: https://www.ncbi.nlm.nih.gov/pubmed/28282846

and motion-sensing cameras for support and assessment of patients with chronic breathing difficulties. [43]

Regarding prevention of diseases, González, S. et al. used a wireless tri-axial accelerometer bracelet to detect walking patterns in elderly people, to prevent disruptive events such as falling and seizure onset.[44] In the same direction, Hsieh et al. developed a fall detection system using an accelerometer device on the waist with about 99% accuracy in identifying falling events.[45]

For mental status monitoring, Setz, C. et al. showed that even simple electrodermal activity sensors have the capacity to identify stress levels.[46]

For breast cancer patients, the Cancer Council Victoria conducted a study with women diagnosed with breast cancer who finished treatment. By using wearable activity monitors (via accelerometers) to measure their physical activity, they found that women in the intervention group increased their physical activity by 70 minutes per week and decreased their sitting time by 40 minutes a day, in comparison with women without any intervention during the evaluation period. Increasing physical activity proved to be beneficial for woman who had suffered breast cancer.[47]

Similar experiments have been held to monitor cardiovascular activity in patients. Ear wearables can be used as an alternative monitoring system, no matter the place or situation a

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[43] Choo, D., Dettman, S., Dowell, R., & Cowan, R. "Talking to toddlers: Drawing on mothers' perceptions of using wearable and mobile technology in the home". In A. Ryan, L. K. Schaper, & S. Whetton (Eds.), Integrating and connecting care: selected papers from the 25th Australian National Health Informatics Conference (HIC 2017) (Vol. 239, pp. 21-27). (Studies in Health Technology and Informatics; Vol. 239). Amsterdam, Netherlands: IOS Press. Available at: https://researchers.mq.edu.au/en/publications/talking-to-toddlers-drawing-on-mothers-perceptions-of-using-weara

[44] Gonzalez S. et al., "Features and models for human activity recognition". Neurocomuting 2015. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0925231215005470

[45] Hsieh CY, Liu KC, Huang CN, Chu WC, Chan CT. "Novel Hierarchical Fall Detection Algorithm Using a Multiphase Fall Model". Sensors (Basel). 2017;17(2):307. Published 2017 Feb 8. Available at: https://www.ncbi.nlm.nih.gov/pubmed/28208694

[46] C. Setz, B. Arnrich, J. Schumm, R. La Marca, G. Tröster and U. Ehlert, "Discriminating Stress From Cognitive Load Using a Wearable EDA Device," in IEEE Transactions on Information Technology in Biomedicine, vol. 14, no. 2, pp. 410-417, March 2010, doi: 10.1109/TITB.2009.2036164. Available at: https://ieeexplore.ieee.org/document/5325784

[47] Lynch, Brigid. "Wearable technology and breast cancer survivors". World Cancer Research Fund International. Available at: https://www.wcrf.org/int/research-we-fund/what-we-re-funding/using-wearable-technology-activity-monitors-increase

specific patient is going through. Da He, D. et al. developed an ear-worn portable ballistocardiogram with this objective. [48]

In a similar path, Goldberg, E. M., and Levy, P. D.[49] demonstrated that wearable trackers have the potential to improve hypertension control and medication adherence through ambulatory blood pressure measuring and medication reminder alerts.

In terms of disease detection, researchers from University of Michigan developed a wearable device that detects cancer in circulating blood. This device, which is in testing phase, "scans" cancer cells. This innovation might replace traditional biopsies[50] for cancer detection which are invasive to the body and generally uncomfortable to the patients.

Wearables are also being used as a tool to help tackle the COVID-19 epidemic. Stanford Healthcare Innovation lab launched a study exploring how data collected from wearables can be used to predict infectious diseases before symptoms start.[51] Stanford Medicine researchers are seeking a series of algorithms that indicates the behavior of the immune system and how it is acting. If the algorithms succeed, the team expects to be able to contribute to curb the spread of viral infections, like COVID-19.[52]

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[48] D. D. He, E. S. Winokur and C. G. Sodini, "An ear-worn continuous ballistocardiogram (BCG) sensor for cardiovascular monitoring," 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, San Diego, CA, 2012, pp. 5030-5033, doi: 10.1109/EMBC.2012.6347123. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4384813/

[49] Goldberg, Elizabeth & Levy, Phillip. (2016). New Approaches to Evaluating and Monitoring Blood Pressure. Current Hypertension Reports. 18. 10.1007/s11906-016-0650-9. Available at: https://www.researchgate.net/publication/301734559_New_Approaches_to_Evaluating_and_Monitoring_Blood_Pressure

[50] Medical News Today. "A new wearable device may detect cancer with more precision". Available at: https://www.medicalnewstoday.com/articles/324855

[51] Miliard, Mike. "Scripps, Stanford working with Fitbit to assess wearables' COVID-19 tracking abilities". April 17, 2020. Healthcare IT News. Available at: https://www.healthcareitnews.com/news/scripps-stanford-working-fibit-assess-wearables-covid-19-tracking-abilities

[52] *Id*.

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