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ORIGINAL PAPER

Multidisciplinary, holistic and patient specific approach to follow up elderly adults

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Abstract Some seniors have medical conditions or lifestyles that put them at higher risk for certain diseases. With increasing age, the human immune system undergoes characteristic changes, termed immunosenescence, which lead to increased incidence and severity of infectious diseases and to insufficient protection following vaccination. One major health issue arising with age is the increasing prevalence and severity of some infectious diseases, which partly reflects the age-related decline in immune function. With the advancements of science and new knowledge regarding diseases, therapies, new drugs and vaccines and particularly new emphasis on wellness through prevention, humans are living longer. The increasing number of elders stresses the healthcare system by requiring more specialists to reach these individuals. On the other hand, new technologies such as wireless networks could give new possibilities for this increased demand by caring for these patients through the monitoring of vital parameters with wearable biomedical sensors, and give them the freedom to be mobile and still be under continuous monitoring, thereby bettering the quality of patient care while also addressing the issue of increased capacity that will be required by caregivers in both developed and developing nations. It is widely acknowledged that, by assisting senior citizens to look after their health at home, their independence can be maintained for longer, providing a higher quality of life for the retiree and lower care costs for the state and the family. A monitoring system could be used to measure several parameters indicating the physical status of the elderly patient. The introduction of such a system into the lives of the elderly can also offer reminders to take medicines, recommend vaccines and immunizations, dietary advice, immediate access to medical professionals and much more. It also reduces the need for visits to a local doctor. The current promising hardware/software platforms for wireless cardiac monitoring could include important measurements such as blood pressure and arterial pulse wave velocity, and have that information directly uploaded to the system.

Keywords Wearable computing · Cardiac monitoring · Telemedicine · Assisted living for the elderly

1 Introduction

We live in an era defined by many challenges, from global warming to global terrorism. None is as certain as global aging, and none is likely to have such a large and enduring effect on the shape of local economies around the world. Aging impact has been more gradual in more developed countries than in less developed countries, affording these nations time to adjust to this structural change. Developing countries will have to cope with population aging and the associated burden of chronic disease before they reach high-income levels.

While this aging trend started in the developed world, it is now a global phenomenon, and it is accelerating, especially in the developing world (Fig. 1). In industrialized countries, the share of those 60-plus has risen from 12 % in 1950 to 22 % today and is expected to reach 32 % (418 million) by 2050. In developing countries, the share of those 60-plus has risen from 6 % in 1950 to 9 % today and is expected to reach 20 % (1.6

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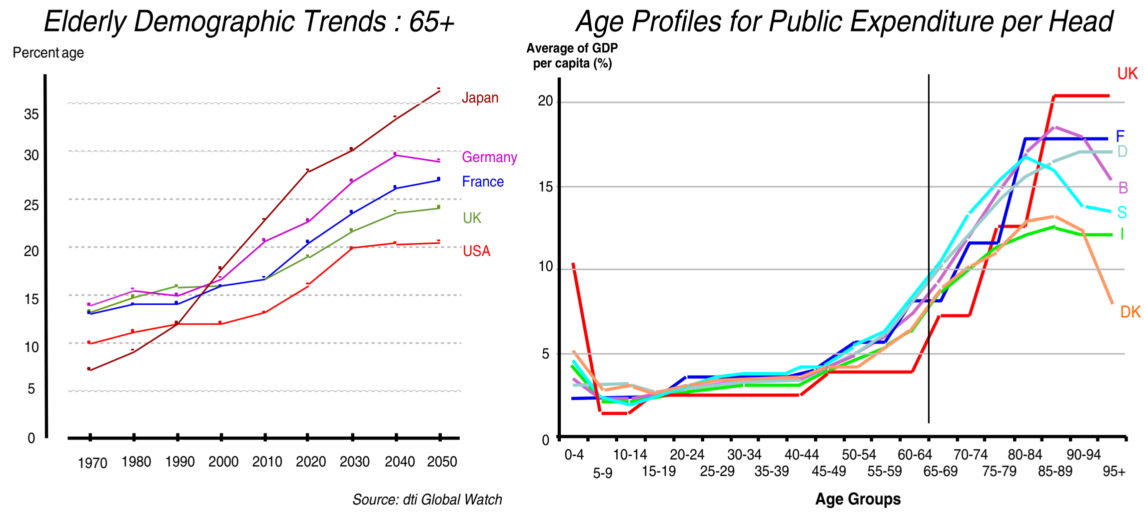

Fig. 1 Elderly demographic change (source: Manning, Bryan and Kun, L. Chapter: "Information Highway to the Home and Back: A Smart Systems Review" p. 17, figure 5). Book: Handbook of Digital Home Care. Editors: Ludowij Bos et al.; Springer, Series in Biomedical Engineering–ISBN 978-3-642-01387-4, October 2009 [2]

billion) by 2050 [1]. The pace of this change means that developing countries will have much briefer periods to adjust and establish the infrastructure and policies necessary to meet the needs of their rapidly shifting demographics. It also means that, unlike developed countries, they will need to cope with more people getting old rather than becoming prosper countries.

The world population on the whole is growing older and wellness and common diseases have been changing. Although many chronic diseases cause serious defects, some studies show that if a healthy life style is adopted and maintained, these defects can be delayed. Moreover, these illnesses generally pose risk factors for individuals and their life styles [3].

Population aging is a worldwide phenomenon, which poses major challenges and opportunities for health economics and geriatrics. Global leaders see a higher cost for social services (see Fig. 1), possible labor shortages, higher costs for pensions and health care as probable outcomes from a larger older population [4]. Few countries will be able to raise enough taxes to cover more than a fraction of the cost of the age wave. Most will have to cut benefits—but the required adjustments are large and are likely to meet growing political resistance from aging electorates. The alternatives: cannibalize other public spending or let fiscal deficits grow.

Cardiovascular disease is one of the most common diseases in elder population (together with chronic lung disease, cancer and diabetes) [1]. Our group has nearly a decade of experience generating epidemiological data of different age groups in South America. Further research is oriented towards cardiovascular disease and other diseases affecting elderly people. Our main focus is to expand the scope of our research, taking on other chronic diseases and incorporating techniques that allow massive diagnostics and remote monitoring of risk groups. In-situ broad scale technology and wearable technology have been tested to ensure the feasibility of this project.

It is widely acknowledged that, by assisting senior citizens to look after their health at home, their independence can be maintained for longer, providing a higher quality of life for the retiree and lower care costs for the state and the family. New wireless technologies could give new possibilities for monitoring vital parameters with wearable biomedical sensors, and give patients the freedom to be mobile and still be under continuous monitoring and thereby better quality of patient care. The introduction of such a system into the lives of the elderly can also offer reminders to recommended vaccines and immunizations to take medicines, dietary advice, immediate access to medical professionals and much more.

Our approach consists of a platform

- For cardiac monitoring in daily life, at rest and during the physical activity of elderly patients.
- To promote screening for the aging population.
- To develop a centralized database to store information obtained noninvasively from anywhere.
- To develop a bio-mathematical model integrating values for cardiovascular risk assessment.
- To generate a patient database related to the healthy elderly population.
- To generate a detailed and comprehensive report for the specialist as well as the primary care physician.
- To create proactively a "preventive cardiovascular environment" which we believe can improve outcomes, quality of life and the cost-effectiveness of treatment.
- To give information on recommended vaccines and immunizations for seniors 65 years of age and older, including information on booster vaccines.

2 System overview

Rapidly aging populations in our region are driving an increasing demand for health care whereas the health care industry has not kept pace with other sectors in making use of information technology. To improve the quality and accuracy of health care, while reducing costs, we must ensure that clinical information and risk evaluation can be shared between authorized caregivers. This can be achieved by introducing interoperable, standardized technologies within traditional points of care. Patients will greatly benefit from better healthcare through the deployment of interoperable electronic health records. Our development of e-health tools serves to detect the alterations of aging and to improve patient treatment through increased knowledge and understanding of that disease by better data linkage, data mining and data analysis; the development of personalized health-risk analysis for patients using biological and health data sets that will improve health outcomes. From an interdisciplinary work that brings together cardiologists, physicists, physiologists and engineers, the development of the program would allow to obtain data to build normal reference tables for structural and functional cardiovascular parameters and to analyze the prevalence and features of aging considering distinctive characteristics of the population.

To start the project application, it was necessary to define three aspects: 1) the technological approach to be used, 2) the non-invasive parameters to be measured and 3) the normal/reference values of the markers to be used. From a technological point of view, we select to use an integrated approach in which complimentary gold-standard techniques and widely used markers were considered in order to obtain structural and functional information about the cardiovascular state of the subject.

2.1 In situ cardiovascular non-invasive evaluation

We opted for an integrated approach in which complimentary, gold-standard, non-invasive and low-cost techniques are applied to obtain parameters used to characterize the structural and functional vascular state (Fig. 2). Sphygmomanometry, applanation tonometry, ultrasound and mechanography are used to measure:

- Internal, External and Common Carotid Artery (ICA, ECA, CCA, respectively) plaque presence.
- Carotid intima media thickness (CIMT) and instantaneous diameter waveforms.
- CCA local distensibility.
- Aortic stiffness (Pulse Wave Velocity).
- Peripheral and central pulse wave analysis.

Recordings and data are stored using the developed application, allowing off-line processing. Detailed data about the non-invasive vascular studies can be found in a previous work [5]. The main characteristics of each parameter are described below.

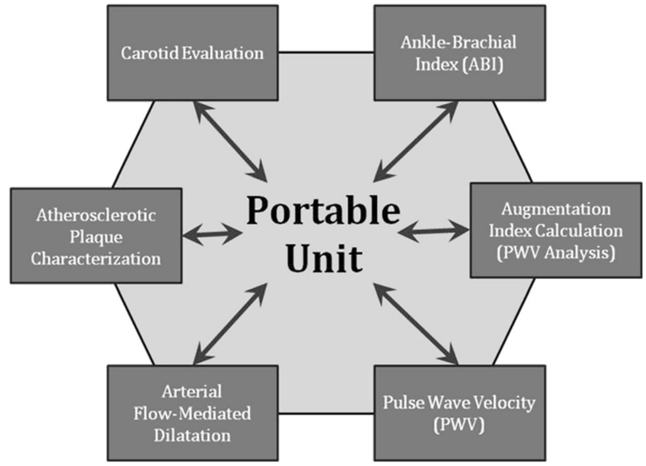

Fig. 2 Schematic diagram of the integrative complimentary approach designed to evaluate arterial structure and function, after medical interview and laboratory measurements. Qualitative and quantitative information obtained/stored in portable (ambulatory) units is transferred (electronically) to a Data Center [4]

Carotid plaque presence and intima-media thickness evaluation Ultrasound evaluations are based on the techniques and recommendations described in international consensus [6]. High-resolution B-mode and Duplex carotid ultrasonography is done with a linear-array, 10 MHz transducer connected to a portable Ultrasound System (MicroMaxx, Sonosite; Bothell, WA, USA). Measurements (still images and video clips/cine loops) are digitally stored for off-line analysis. Studies are done after 10-15 min of recumbent rest. Before and during ultrasound examination (at 3-min intervals), brachial blood pressure measurements are obtained using an oscillometric device (Omron HEM-433INT Oscillometric System; Omron Healthcare Inc., Illinois, USA).

Transverse and longitudinal views of the proximal CCA to the peripheral segments of the ICA and the ECA are obtained, so as to assess the presence of atherosclerotic plaques. Near and far walls are analyzed and images are obtained from anterior, lateral and posterior angles. A carotid atherosclerotic plaque is defined as focal wall thickening at least 50 % greater than that of the surrounding vessel, a thickening that protrudes into the lumen 0.5 mm or as a region with CIMT greater than 1.5 mm [5, 6]. Plaque thickness is quantified at the site of maximal encroachment perpendicular to the vessel wall, and obtained by measuring (digital calipers and automated procedures) the distance between the media-adventitia interface and the lesion surface facing the lumen.

After plaque screening, longitudinal views of the CCA (obtained at the described angles), are acquired so as to measure the CIMT. A video (cine-loop) of at least 10 s is recorded from each angle of interrogation. The CIMT and beat-to-beat diameter waveforms are obtained and analyzed off-line using a specifically developed step-by-step border detection algorithm applied to each digitized image (Hemodyn4M software, Buenos Aires, Argentina) [5, 7]. A region 1.0 cm proximal to the carotid bulb is identified, and the far wall CIMT determined as the distance between the lumen-intima and the media-adventitia interfaces. If there are plaques in the area of CIMT measurement, they are included in the measurement. The used software performs multiple automated or semi-automated measurements along 1 cm and averages them, increasing the measures accuracy (see Fig. 2).

CCA local stiffness To evaluate the CCA stiffness we calculated parameters that give complementary information about the vascular behavior [8, 9]. The considered stiffness indexes are commonly used in clinical practice, since they can be obtained using only systolic (maximal) and diastolic (minimal) diameter and/or pressure values measured by Applanation Tonometry (PWA, SphygmoCor, AtCor Medical Pty Ltd., Sydney, Australia).

Regional aortic stiffness (carotid-femoral pulse wave velocity) Carotid-femoral pulse-wave velocity is measured to analyze aortic regional stiffness. To this end, using mechano-transducers placed simultaneously on the skin over the carotid and femoral arteries (subjects in supine position), carotid and femoral pulse waves are recorded (Hemodyn 4 M, Buenos Aires, Argentina) [4, 6].

Peripheral and central (aortic) pulse wave analysis Pulse wave analysis (PWA) is used to obtain the ascending aortic pressure waveform from the radial pulse (obtained by Applanation Tonometry) using customized software (SphygmoCor 7.01, AtCor Medical, Sydney, Australia) with a previously validated generalized transfer function [8, 9]. The radial pulse waveform is calibrated using diastolic and mean brachial pressures (Omron HEM-433INT Oscillometric System; Omron Healthcare Inc., Illinois, USA) [9]. Central arterial pressure is estimated from the aortic pulse wave, and indexes of wave reflection are quantified from the analysis of central and peripheral pressure waveforms.

Peripheral and central (aortic) pulse wave analysis Pulse wave analysis (PWA) is used to obtain the ascending aortic pressure waveform from the radial pulse (obtained by Applanation Tonometry) using a computerized tool to load, store and process data. Users capable of managing data with different faculties/views and operating at different locations (technicians, specialists and administrator) are defined.

2.2 Wearable technology for elderly patient

Recent advancement in wireless communication and Smartphone technology has empowered tremendous improvement in health monitoring services. These technologies have the potential to revolutionize patient care. Ultimately, this approach could help fewer health professionals deliver more effective care to more patients at reduced cost. It could provide behavioral feedback about the health of an individual in order to prevent diseases. Its bases are listed below. See Fig. 3:

- Vital signs are the most basic functions that can be measured from a person.
- Providing health monitoring at home is particularly useful for patients who live alone.
- The measurement of biomedical signals and activities of patients can be achieved automatically and unobtrusively.
- Ubiquitous health monitoring is an important precursor for analysis and diagnosis, as it allows biomedical signals to be measured without the individual being aware of it.
- Routine exercise can be monitored on a day to day basis

The smart sensor is a wearable system that monitors the physical activity of the patient. It is based on smart-fabric technology, microelectronics and wireless communications. Gow Running [2, 10], is a comfortable compression shirt made of ultra sensitive material, integrating sensors that can detect cardiac activity and respiration rate, two essential parameters to know the intensity of the effort carried out by the user. The embedded microelectronic device gathers and processes all the signals sensed by the shirt. The output data are: ECG (one lead), heart rate (HR), RR interval (RR), movement (movement classification, speed and rhythm), respiration rate and quality signal index. Data is either transmitted via Bluetooth to a mobile phone or PC, or stored in its internal SD memory. The fabric is designed to provide more effective

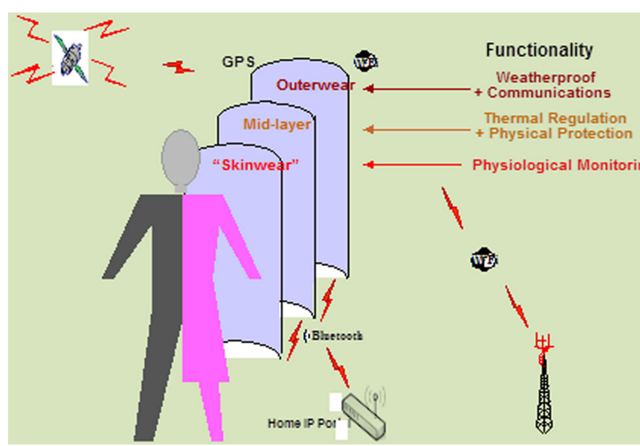

Fig. 3 Smart wearables—a mobile communications and monitoring platform source: Manning, Bryan and Kun, L. Chapter: "Information Highway to the Home and Back: A Smart Systems Review" p. 24, figure 9. Book: Handbook of Digital Home Care. Editors: Ludowijk Bos et al.; Springer, Series in Biomedical Engineering- ISBN 978-3-642-01387-4, October 2009 [2]

evaporative surface. The yarns with multi channel surface provide an outstanding dissipation of moisture. Hollow fibers allow an enhanced air circulation and focus energy on the evaporation process.

The systems provide enriched data to both the patient and the physician: ECG and HR plots, HRV, VO2, Calories, Time (total and partial), speed, rhythm, GPS position, slope and more. These data can be complemented with Blood Pressure and Body Weight measurements.

The TSB's [11] technological solution that implements multifactorial and comprehensive long-term care program for CR and secondary prevention: clinical support, optimized medical management, appropriate cardiovascular risk evaluation, education and counseling, and exercise training and nutritional advice. Supports "in-house" (at the hospital) services and "at-distance" (on-line everywhere-anytime).

3 Conclusions

The success story of population aging and longer lives is often accompanied, in the end, by tales of doom and gloom; but it is vital that the global community does not succumb. Although there are serious challenges, which must be weighed, understood, and in some cases adapted to, there are also enormous opportunities that must be seized.

Studies on wellness and the prevention of diseases have been found effective, especially in providing lifelong behavioral change. Since the elderly population is at a huge risk of major diseases and defects, members of health care units should handle their education carefully. Through such education, benefits are provided regarding protective and wellness development for many elderly people [3]. According to the data from World Health Organization, worldwide obesity increased over 200 % since 1980 [12]. It has been proven that obesity can cause coronary heart disease, type-2 diabetes, and various types of cancers [13]. Cycling exercise equipment is frequently utilized to facilitate upper and lower extremity training and it is widely available in rehabilitation facilities where the patient exercise may be supervised [14]. The cycling exercise training has been shown to improve clinical outcomes in patients with chronic health conditions and promote rehabilitation in older adults and is shown beneficial for patients recently weaned from mechanical ventilation, patients in post-acute recovery phase after hip fracture, dialysis patients during hemodialysis sessions, and in active elderly [15]. Medication adherence, i.e. the degree to which patient behavior coincides with therapeutic regimen plays a major role for the success of drug-based therapies. The lack of adherence may cause worsening of the health of patients in general, increase the risks of hospitalization [16] and, as a consequence, also increase costs [17].

The main objectives of this program are:

- To obtain reliable, valid and comparable data on levels of health on a range of key domains for older adult populations.
- To examine patterns and dynamics of age-related changes in health using a longitudinal design.
- To supplement and cross-validate self-reported measures of health and the anchoring vignette approach to improving comparability of self-reported measures, through measured performance tests for selected health domains.
- To collect data on health examinations and biomarkers to improve reliability of data on morbidity, risk factors and monitor effect of interventions.

Our secondary objectives are

- To enhances focus on the prevention and early management of health problems over the life course;
- To reduce unnecessary and potentially harmful specialist care;
- To include educational contents like social networking.

We prefer to opt for technologies that can be applied in national screening programs, i.e. in large populations. It is therefore necessary to have portable equipment that allows access to people in their own environment (Fig. 4). As a law,

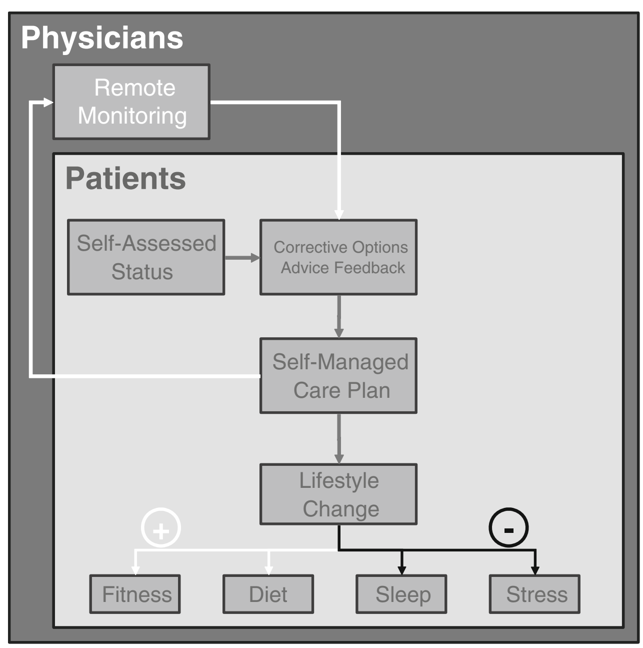

Fig. 4 Supported self-care adapted from: Manning, Bryan and Kun, L. Chapter: "Information Highway to the Home and Back: A Smart Systems Review" p20. Figure 7. Book: Handbook of Digital Home Care. Editors: Ludowijk Bos et al.; Springer, Series in Biomedical Engineering- ISBN 978-3-642-01387-4, October 2009 [2]

the best policy for prevention and early diagnosis will be that cause less inconvenience to people.

Finally, in spite of its emergence as a useful tool for aging alterations, assessment a widespread implementation of aging markers evaluation has been hampered, among other factors, due to the absence of a standardized methodology of study, and due to the lack of established normal and reference values for different populations. Related with this, taking into account the complexity of age-vascular disease interaction, an important issue would be the characterization of the structural and functional vascular changes associated with aging. Such information would contribute to differentiate abnormal or disease-related vascular changes and those expected due to aging.

4 Future perspectives

The vision of the project is supplemented by its ambition to provide clinical doctors with tools that will be able to support them before, during and after a clinical intervention. In other words, our aim is to support cardiologists in clinical practice by assisting them to select appropriate therapeutics based on the patient structural and functional cardiovascular behavior.

Age-related structural and functional cardiovascular parameters profiles are obtained in the context of the present project, using gold standard methodologies and techniques taking into account available data from other populations. The work has the strength of being the first in Latin America to apply an integrative approach to characterize age-related structural and functional parameters.

Further studies will be necessary to include a new generation of sensors based on the measurement of central pulse wave velocity values. Because of its non-occlusiveness, this new generation of sensors is prone to be easily integrated in ambulatory and wearable measurement setups. The introduction of such a system into the lives of the elderly can also offer reminders to take medicines, dietary advice, immediate access to medical professionals and much more. It also reduces the need for visits to a local doctor.

The current promising hardware/software platforms for wireless cardiac monitoring could include important measurements such as their blood pressure, arterial pulse wave velocity and have that information directly uploaded to the system. Any healthcare professional they deal with can therefore have immediate access to their recent health records.

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Conflict of interest The authors declare that they have no conflict of interest.

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