Clinical Interventions in Aging

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PERSPECTIVES

Delphi Assessment of Home-Based Digital Healthcare for Aging Patients: A Biopsychosocial Perspective

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Purpose: The development of home-based clinical interventions and healthcare supported by digital tools has rapidly advanced in recent years, promising improvements in preventive and personalized treatment, especially for aging chronic patients. However, many systems are launched without feedback from healthcare experts, essential for understanding their strengths, limitations, and areas for improvement. This study had two objectives: first, to gather expert opinions on the qualities and limitations of current home-centred healthcare trends for aging patients; second, as a case study, to obtain feedback on a novel system, *Time-Integrated Healthcare* (TI-Health), integrating these trends. TI-Health uses real-time data to combine bio-psycho-social information through big data and machine learning, enabling health status prediction, diagnosis, prevention, and treatment.

Participants and Methods: A Delphi group of 60 experts from 9 countries, all with experience using digital health systems, was surveyed. A questionnaire was administered to the group focused on the limitations and qualities of current home-based digital healthcare trends. In addition, the Delphi group provided feedback on the TI-Health system.

Results: A majority of experts believed that personalized healthcare delivered in the patient's home will shape the future of healthcare services. The Delphi group identified key qualities of these trends: improved service integration, enhanced patient comfort, cost reduction, and a deeper understanding of the patient's context. They also highlighted challenges, such as barriers to inter-agency collaboration and data sharing, resistance to change among healthcare professionals, and the need for strong leadership to drive the adoption of new systems. Based on the insights from the Delphi group, this work presents a refined conceptualization of the TI-Health system.

Conclusion: Designing home-based clinical systems such as *TI-Health* should prioritize effective inter-agency coordination, ensuring data protection and fostering collaborative leadership throughout the implementation process. These factors are crucial to the successful adoption and utilization of new home-based digital health solutions.

Keywords: predictive-health, digital-health, aging healthcare, telemedicine, digital health governance

Introduction

Traditional illness-oriented healthcare models, treating the person once the disease symptoms are manifested, imply a recognized failure in our health system, as we treat the individual disease, but we do not treat health.[1,2] Current trends in home-based healthcare are grounded on the concept that health services are most effective when tailored to the persons in their natural context within preventive health-centric approaches.[1,3–5] The use of digital information and communication technology (ICT) and artificial intelligence (AI) tools in ambulatory care is driving an increased interest in home-based healthcare as a substitute for or in combination with inpatient care under different conditions.[1,6–9] The COVID-19

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pandemic has dramatically increased the interest in switching the view of health services to aging patients' homes as the best approach to protect them and, in so doing, to optimize their health status.

A common aim of current trends in home-based healthcare for the aging person is to preserve individual and family autonomy and wellbeing using an integrated and holistic concept of health. This involves focusing on the effective prevention of illness and the promotion of health. It requires the integration of biological, physiological, psychological, and contextual multidimensional factors, which should not be considered in isolation if the goal is to achieve a comprehensive and accurate diagnosis and treatment. Many of these current trends are based on approaches such as:

1. E-health methods for prediction and early diagnosis that increase healthcare cost-efficiency and effectiveness.[2,3,10–14]
2. Home-based and ambulatory telehealth information for diagnostics and treatment in the natural context where problems and solutions may be pinpointed, preserving wellbeing, autonomy, and emotional support in the patient while increasing the cost-effectiveness of health services.[6,7,15,16]
3. Integrative healthcare systems, including information from formal/informal community resources and services available in the patient's context. Current research shows the effectiveness of patient-based integrative care models based on health governance and preventive approaches tackling all main factors affecting a disease in a systemic approach, compared to traditional inpatient and specialized services.[1,17] These integrative solutions include features such as: Real-time information monitoring and prediction on the patients' health;[1,2] health information e-governance, with the collaboration of all formal and informal resources;[1,18,19] patient-centered and community-based management models allowing decentralized inter-agency integration of information;[6,7,20,21] tools to facilitate self-management health aimed at strengthening empowerment and increasing the perception of self-efficacy and control over the patient's health;[22,23] shared healthcare tools aimed at merging information from all stakeholders;[6,7] digital health ecosystems and cross-health services tackling the health value chain between the front-end and back-end technology.

The current home-based healthcare models also build on different types of e-health, digital technology and knowledge management (KM) systems, processing large amounts of real-time, multidimensional information from/to the patient's home. Digital tools include innovative smart wearable technologies (SWT), contactless physiological data, motion algorithms, artificial intelligence, and KM applications. Some examples of companies and products delivering such services are:

1. Traditional home automation (eg, Taking Care, EnvoyatHome, Aloe Care Health, and People Power Family);
2. Camera-based systems (eg, Nobi, SmartPeep, and Standford Partnership);
3. Contactless methods (eg, Farosense, Qumea, Aeyesafe, and Origin wireless AI);
4. Wearable technologies (eg, CarePredict and Kibi).

The combination of early disease detection with time-based approaches in home-based care provides a system to protect the patient, preventing the emergency or crisis often experienced by older patients. The need to bring about a fast and early response has been evident in the Covid-19 pandemic crisis. Evidence especially shows this need in environments such as nursing homes, where many times there are limitations in medical monitoring systems available and connection to the health system.[24,25]

Despite the attractive prospects presented by the emergence of novel artificial intelligence (AI) applications and devices for remote health diagnosis and monitoring, the efficacy of these home-based systems should not be taken for granted. Current e-health devices and systems are still predominantly used in the context of inpatient diagnosis and monitoring. These systems are gradually entering the field of ambulatory and home healthcare, and in most cases there is a lack of clarity regarding their clinical effectiveness and the impact on patient well-being.[26–29] Moreover, many of the digital technology applications for home healthcare are still under development, often lacking inter-disciplinary teams and multi-stakeholder perspectives. Still centering on the person's illness, there is a lack of deeper interdisciplinary valuation of their effectiveness of data analysis for diagnosis and prognosis and on the levels of the patient's acceptance.[30–33] Small teams design most home-based digital healthcare systems without the shared participation, input, and feedback of professionals and experts in different fields (medicine, health management, telecommunication and computer engineering, economy, and other health fields). This participation and feedback are fundamental for the new systems' optimal development, acceptance, and implementation. There is a need to advance the development of integrative digital health diagnostics and treatment systems based on health-centric frameworks, including the participation of users, practitioners, and experts from different fields.[1,2,9,34]

To contribute to covering this need, the aim of the present study is to gather the views of experts in different healthcare-related fields about the current trends on home-based digital healthcare and clinical intervention. Experts also assessed a novel integrative healthcare system, Time-Integrated Healthcare System (TI-Health), at the stage of designing, as a concrete example. The initial TI-Health system was built by the authors of this work with the collaboration of medical, computer, social, and psychology experts from 11 countries (Spain, United Kingdom, Austria, Poland, France, Belgium, USA, Greece, Germany, Netherlands, and the Czech Republic). It merged key components of the current trends in home-based integrative digital healthcare.[1] The proposed TI-Health system represents a comprehensive and integrative framework for healthcare management and service provision. It is primarily aimed at enhancing the wellbeing of health communities, with a particular focus on aging populations. The system seeks to achieve high precision in early diagnosis and predictive capabilities while simultaneously improving the cost-efficiency of healthcare services. It includes time-based monitoring of (genetic, physiological, psychological, and social) risk factors, facilitating a better personalized and integrative preventive treatment tacking those factors. A differential property of TI-Health compared to other home-based healthcare systems is the time-integrated automatic learning data processing, embedded into an interoperable big-data information management system.

The main objective of this study is to gather experts' perspectives from various fields on current home-based digital health systems and clinical interventions in comparison to traditional inpatient healthcare. It also aims to explore ways to improve the feasibility, cost-efficiency, and effectiveness of these digital health approaches. The study aims to have an interdisciplinary knowledge of the limitations, challenges, and qualities of these current approaches to advance in developing these systems. Based on the Delphi group´s feedback, a refined TI-Health system is briefly described and discussed.

Materials and Methods

Sample

Sixty experts from different health fields (medicine, computer engineering, telecommunication engineering, health management, and other health-related fields) were selected to compose the final Delphi group, based on the relevance of their publications or on their large experience in the use of home-based digital healthcare systems. Medical doctors were the most frequent profession (38%), followed by computer engineers (31%) (see Figure 1). Figure 2 displays the place of work of the experts, with public health institutions being the most common (31%). The mean age was 53, with 72% men and 28% women working in health centers in Spain, Poland, Hungary, Greece, Slovenia, Belgium, Italy, Portugal, and Switzerland.

Tools

A questionnaire was designed to assess the extent to which current trends in personalized, home-based, preventive clinical interventions will shape the future healthcare system, and the strengths and limitations of existing home-based digital healthcare trends. The survey instrument was developed based on a thorough literature review and expert consultation to ensure item clarity and relevance prior to distribution. The items regarding the strengths and limitations of these trends displayed a list of the most common qualities and limitations pointed out in the scientific literature in the field. The participants were asked to select up to three 3 qualities and up to 3 limitations and challenges. Also, open-ended questions were allowed to answer "other" limitations, challenges, and qualities. Moreover, a synopsis of the TI-Health system was furnished for the purpose of its evaluation. The Delphi group was invited to provide an assessment

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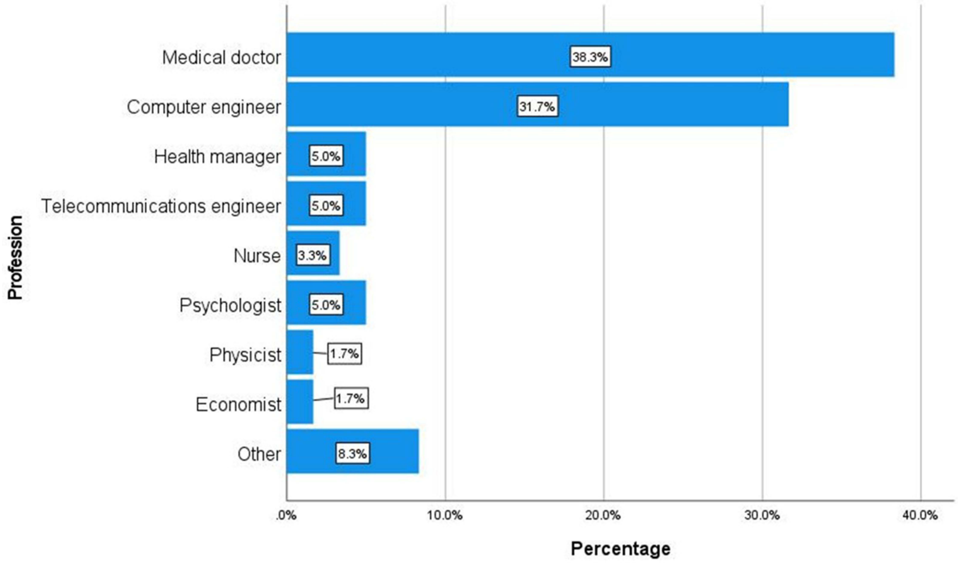

Figure 1 Professions of the experts in the Delphi group.

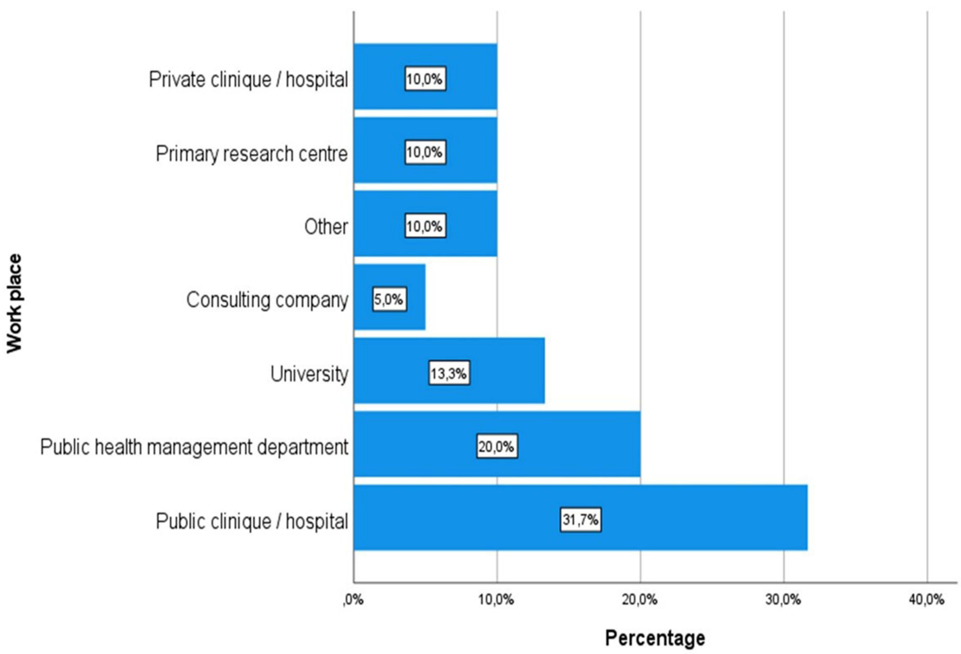

Figure 2 Place of work of the experts in the Delphi group.

and a feedback on measures to enhance the TI-Health system. The enquiry concerning the provision of feedback to enhance the TI-Health system was posed without an extension limit (refer to the questionnaire, which contains a link to the synopsis of the TI-Health system, in the Supplementary Material). Questions regarding demographic (age, sex) and professional (field of profession and place of work) information were added.

The questionnaire stated a data protection guarantee submitted to the EU 2016/679 regulation of the European Parliament and Council on April 27th, 2016. The study followed ethical procedures by the Declaration of Helsinki[35] and had the approval of the Research Ethical Committee at the Complutense University of Madrid (ref. No. CE_20230511-08_SAL).

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Procedure and Data Analysis

The questionnaire was administered in a single round. Although the classical Delphi technique typically involves multiple rounds to achieve consensus, a modified approach was used in this study. The initial development of the TI-Health system was conducted with input from a separate expert panel using also a Delphi process. Given that the findings from the current group aligned with those of the previous panel, conducting additional rounds was deemed unnecessary. This approach aligns with accepted modifications of the Delphi method when prior consensus exists and item stability has been demonstrated.[36,37] A link to the questionnaire was sent through an online invitation. All participants provided informed consent before completing the questionnaire. All Delphi members' inputs were gathered within a six-month timeframe. The data was processed using the SPSS statistical package. Descriptive statistics were obtained on all the closed items. Questions regarding the extent to which current trends towards personalized, home-based, preventive clinical intervention are perceived as the future of healthcare were assessed using the Chi-square test ($p < 0.05$ accepted as significant).

The open-ended answers regarding the assessment of the TI-Health system were processed using a qualitative methodology, by categorizing the responses based on similar meanings, carried out independently by three researchers. Disagreements on the resulting categories were discussed to reach a consensus. Based on the answers, the categories were related into a semantic network using the same procedure to reach consensus by the three researchers. The digital program Atlas.ti was used to process the information.

Results

Regarding the perception on the future healthcare and clinical intervention, a significant majority of experts reported that personalized healthcare in the patient´s home and community will be the base health service in the future (50% reported "quite a lot", and 18.3% "completely") (Chi-square = 9.1; $p = 0.01$) (see Figure 3A). Also, 50% of the experts found that the health services will be basically centered on predicting and preventing diseases in the near future (Chi-square = 27.7; $p<0.001$) (see Figure 3B). Figure 4 shows the main qualities and limitations of the current trends in healthcare based on personalized, predictive, community- and home-based services supported by digital technologies as selected by the participants. The most cited qualities were as follows: (1) an improvement in the integration of services in the relationship with the patient (16.8% of all the total selected qualities); (2) a more comfortable service for the patient (15.1%); (3) a reduction in costs of the health services (14.6%); (4) a better understanding of the patient´s context (13%), and (5) the predictive ability of machine-learning systems based on bio-psycho-social approaches (11.9%). Regarding limitations, the most cited ones were as follows: (1) the resistance to change of the practitioners to implement the new system (22.3% of all the cited limitations); (2) data protection within a health e-governance approach (14.9%); (3) difficulties in sharing information among different agencies (12.6%); and (4) lack of effective leadership to implement the changes (12%).

Regarding the feedback of the Delphi group on the TI-Health system, Figure 5 shows a semantic network of the relationship among the categories of elements pointed out by the group to improve the system. The three core categories of challenges were as follows: (1) Need for collaborative leadership in change management; (2) perception of intrusiveness/need to preserve patient's autonomy and freedom; and (3) insufficient knowledge and expertise.

Discussion

Most experts pointed to the community- and home-based trends as the future healthcare approach. There is not such a majority regarding to what extent the health services will be basically centered on predicting and preventing diseases in the near future (50%). This lower confidence in the feasibility of predicting and preventing diseases in the near future can be explained in the responses given to the following questions. Whereas they did not find notable limitations of the new systems, they especially stressed the current difficulties to implement them. The results indicate the importance of an effective leadership in implementing a successful system, addressing practitioner resistance to change, and ensuring stakeholder and patient involvement. They also highlighted the challenges of establishing an inter-agency and governance environment, particularly in data protection, sharing and integration. The Delphi group also expressed that even though a system such as TI-Health gathers the main elements of the future healthcare, they find a series of challenges that

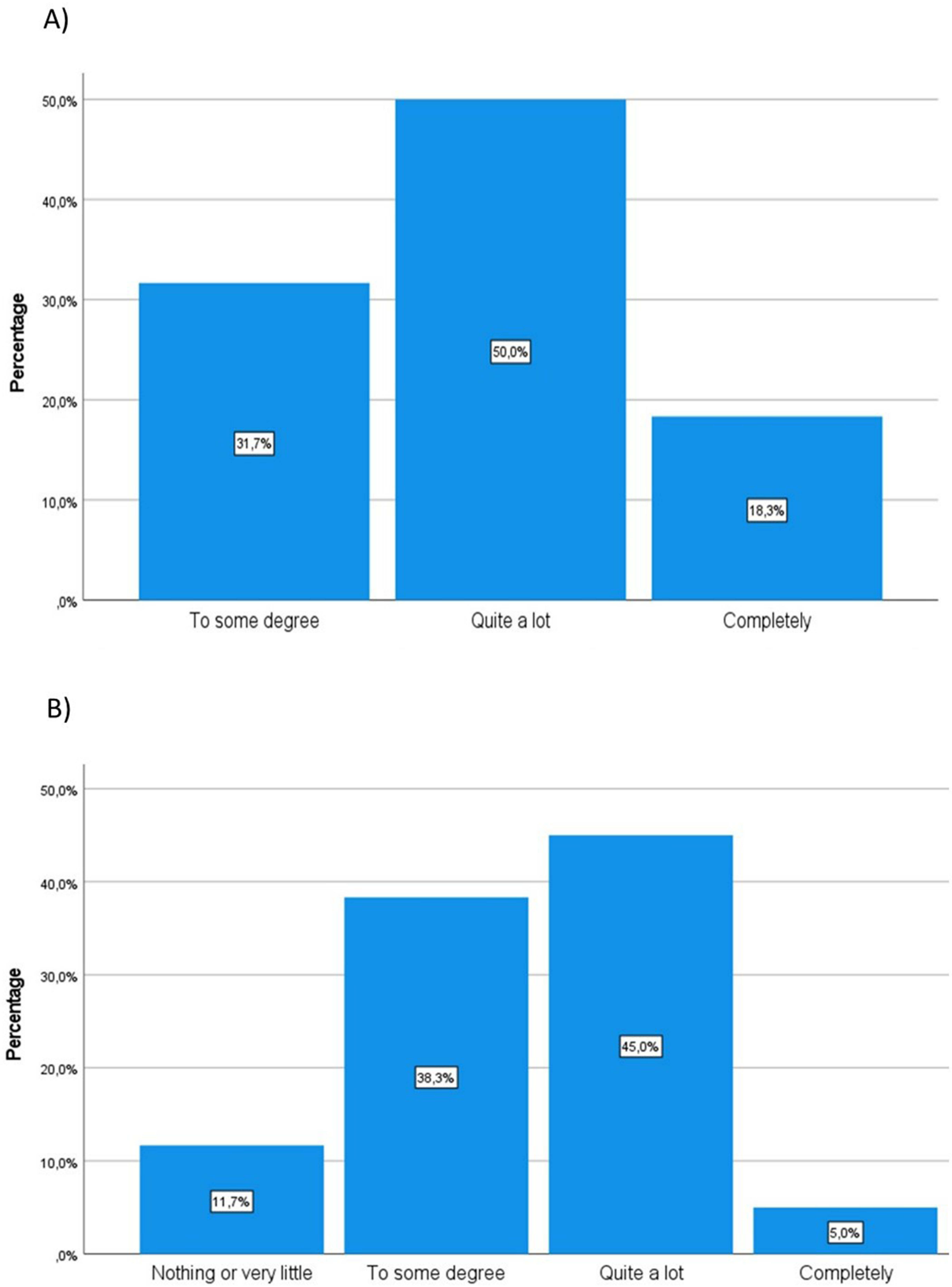

Figure 3 Percentages of answers to central questions regarding the relevance of the current trends based on personalized, home-based healthcare. (**A**) To what extent will personalised healthcare in the patient's home be the basis of healthcare services in the future? (**B**) To what extent will health services be centred on predicting and preventing diseases in the near future?.

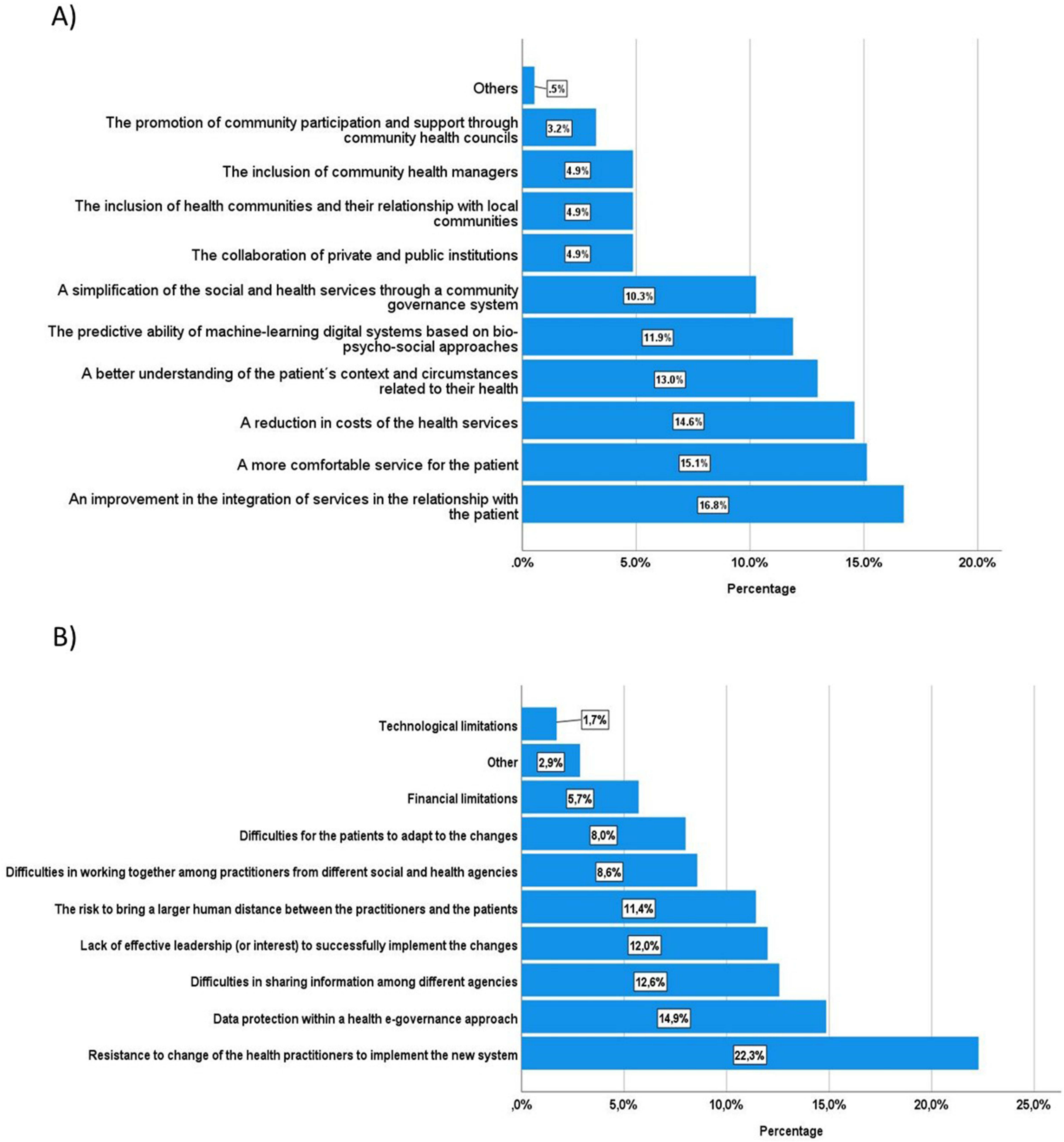

Figure 4 Main qualities and limitations of the current trends in healthcare based on personalized, predictive, and community, home-based approaches supported by digital technologies. (**A**) Main qualities (percentage of each quality out of the total number of qualities selected by the Delphi group). (**B**) Main limitations (percentage of each limitation out of the total number of limitations selected by the Delphi group).

need to be approached. They emphasized the challenges of obtaining the requisite management and leadership to facilitate collaboration among institutions and to address resistance to change, as well as the insufficiency of knowledge and expertise in the field. Equally important is to implement a fundamental patient-centered approach with the acceptance by the patients as they may perceive the system as intrusive and complicated, as found in other studies.[9,32]

In general, the new home-based healthcare systems should incorporate elements and strategies to face the resistance and reluctance to implement them. This may be achieved by further training of health and social practitioners and by

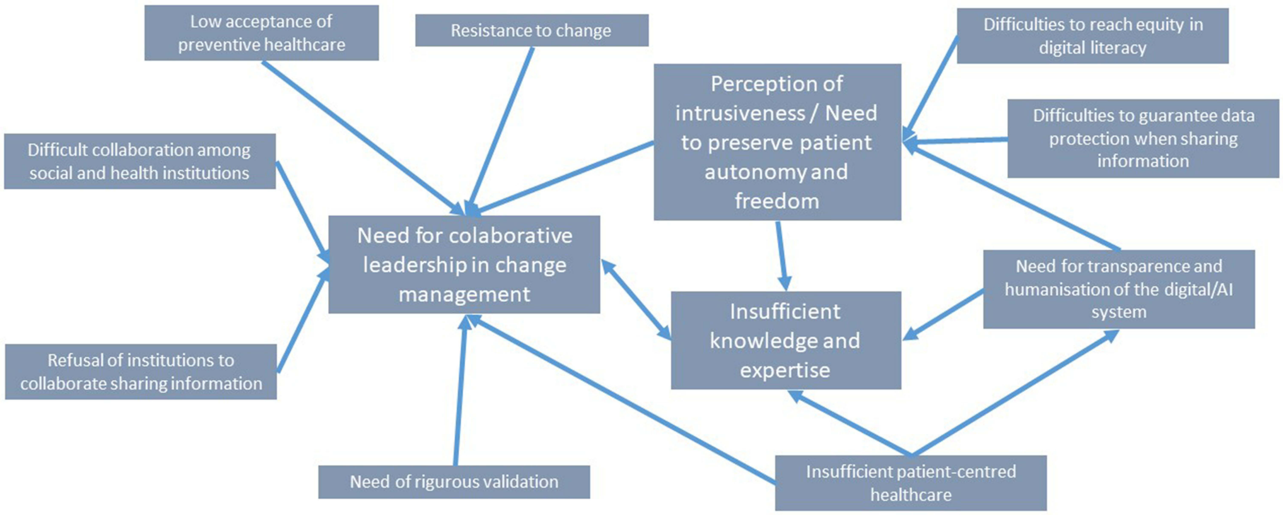

Figure 5 Semantic network of the relationships among factors identified by the Delphi group to improve the system.

fostering the participation of patients in the entire system implementation process. A collaborative leadership style of management should be present throughout the system implementation process.

Next, an outline of the main points of a refined TI-Health system is described, based on the issues underlined by the experts' feedback in this study.

A Framework for a Home- and Community-Based E-Healthcare System

In light of the Delphi group's contributions, the following areas are identified as key priorities for advancement in the realm of home-based digital healthcare systems, such as TI-Health.

Approaching an Effective Leadership for a Community Health Governance

The input of the Delphi group in this study points to the need to advance in person-centered healthcare systems using a relational management model based on participatory and horizontal governance. To do so, the role of the community health manager is key to making the system more effective. A community health management may use collaborative leadership skills to relate the persons with the local health communities and agencies (health centers, social services, housing, economy, environment, culture, and leisure), integrating information and communication in the close relationship with the patient, fostering health communities, collective intelligence and information governance.[1]

Approaching Resistance to Change

Frequently, in health centers practitioners question why the system should be changed if it works well. They may feel their work is being questioned if they need to change it. Through participatory workshops with practitioners from different fields and using creativity techniques, they should be made participants in the process of change from the beginning. These workshops should facilitate practitioners' awareness of the benefits of the new system, including an improvement in efficiency and effectiveness. Understanding the person in their context is the key concept for a complete diagnosis to facilitate the most effective prevention and treatment of disorders in the aging person, always by the principles of Personalized and Precision Medicine (PPM).

Providing home-based services drastically improves the cost-efficiency of health services, as it preserves patients' autonomy, reduces hospitalization, and provides knowledge about the informal and community resources that empower them.[6–9,19–21] Once implemented, the system facilitates each practitioner's work by working in teams with other practitioners from different fields. Relational management, community governance, and collaborative leadership also facilitate the work of health practitioners to follow and support the evolution of health for an optimal quality of life through all the stages of the aging journey.[1,18,19] Integrating patient's, practitioners', caregivers', and stakeholders' information in the close relationship with the patient will, in turn, allow a more practical approach to treatment and prevention. Making all these points visible from the beginning may reduce resistance to change in health practitioners and managers.

Approaching the Participation of Patients and Stakeholders

The digital-supported platform shall use the "counting on you" messages to the patients, caregivers, and other stakeholders. Patients' involvement and participation will bring the possibility of a joint, deliberate, thoughtful, intelligent, informed, discussed, and mutually agreed co-production and co-management of their health information in selecting the type of healthcare that is most desired and needed, especially in patients with risks and vulnerabilities of disorders. Collective intelligence and KM for diagnostics among agencies and community participation will contribute to co-creating more accurate anticipatory treatment programs and monitoring them to prevent and treat disorders. Interoperable ICT/KM systems in the project will allow decentralized information storage while allowing a collaborative analysis of information and decision-making, together with data protection and confidentiality strategies. Making patients and caretakers fully participating in the process promotes better knowledge and higher commitment to health treatment. Digital technology must foster a better, higher quality of face-to-face relationships with those in need when they need them, within a mixed tele- and face-to-face care environment.[19]

Acceptance of the system is underlined in this study. Specific acceptance strategies for a SWT-based health system is to be achieved through a co-creation process involving patient participation. This approach will ensure the adaptation of the system to meet the needs of the patient, facilitating its use in a more accessible and user-friendly manner.

Approaching Inter-Agency Collaboration for Adequate Data Integration and Processing

The home-based healthcare system should integrate heterogeneous information from different sources to get a complete dynamic "picture" of the patient's health. The integrated information management model should be tailored to each case, facilitating the patient's acceptance and optimal treatments earlier during a disorder development and preventing further relapses and ongoing disability.

To achieve high precision in diagnostics, we must describe the complexity of health components and their dynamic relationships, personalized for each individual, as outlined by PPM. A patient-centered healthcare system focuses on the patient's environment and unique characteristics, tailoring diagnostics, treatment, and prevention. This requires a governance system that integrates information from health and social agencies.

Health centers and social agencies often generate valuable data for early detection but store it in silos, limiting its use. Digital systems enable data integration, helping identify individuals or groups needing integrated healthcare. By using interoperable information management systems based on international open standards,[38] health organizations can implement coordinated care programs. This facilitates further simplification of organizational structures and processes.[1] This system provides a holistic view of health, supporting effective planning for public health and the prediction and prevention of health issues. This information shall include dynamics between health protective factors and risk factors for effective detection, prediction, and prevention of all health-related problems.

Community health managers are responsible for ensuring that information gathered from various sources is properly integrated into patient interactions while maintaining data protection and confidentiality. They must ensure that agencies and stakeholders use the information appropriately. The system may allow agencies and patients to share information with other agencies and citizens, but only the data needed, in compliance with data protection regulations. Confidentiality will be managed with access filters based on the services, agencies, and users involved. A key strategy is to maintain a federated distribution of information across the servers of the agencies that own the data, integrating it not into centralized storage, but as "neural networks." This local integration will support patient data rights and sovereignty.

All information must flow in the interaction with the patient. Smart Wearable Technology (SWT) is a non-invasive technology for remote, semi-permanent, unobtrusive, and real-time recording of physiological data (such as heart rate, blood pressure, skin conductance, respiratory rate and volume, etc.) virtually without discomfort, allowing the person to do their habitual daily activities while being monitored and guarded. SWT can keep 24-hour monitoring of the person's health for early diagnosis. Clinicians can collect input information from patients and then output it when necessary in the big database associated with the SWT system. With continuously aggregated patient information collected in the database, machine-learning tools included in software applications may constantly update and improve health trends, increasing the accuracy of predicting disease symptoms, risks, and outbreaks. Thus, the result should be better patient´s healthcare, autonomy, and operational efficiency. Easy-to-use features allow patients to access information at any time with explanatory information and recommendations.

Prediction means time. Systems like TI-Health enable real-time monitoring and analysis of patients' conditions to predict health issues and allow early intervention. Advanced digital technology integrates a wide range of bio-psycho-social data, including physiological measures (such as heart rate, blood pressure, respiratory rate, oxygen and CO2 levels), demographic and behavioral factors, psychological markers, therapy types, and health management details. It also tracks disease severity, relapse symptoms, comorbidities, physical and mental health impact, quality of life, cognitive decline, disability levels, and social support through self-reports and questionnaires from patients, caregivers, and healthcare providers.

The predictive software of the TI-Health model is based on a machine-learning approach using past data of bio-psycho-social indices across time to generate health patterns that may predict future "analog" conditions. Going beyond "one-shot" diagnostics and prognosis, the machine-learning applications will continuously screen how time patterns among health indices predict other time patterns on the evolution of a person's health and how these time-patterns predictions may be analog to those time-patterns predictions of different disease groups (see Figure 6). Real-time, continuous machine-learning work implies a constant adjustment to the person's health evolution and a continuous improvement in precision in early diagnosis and prediction. These predictive disease time patterns will automatically and

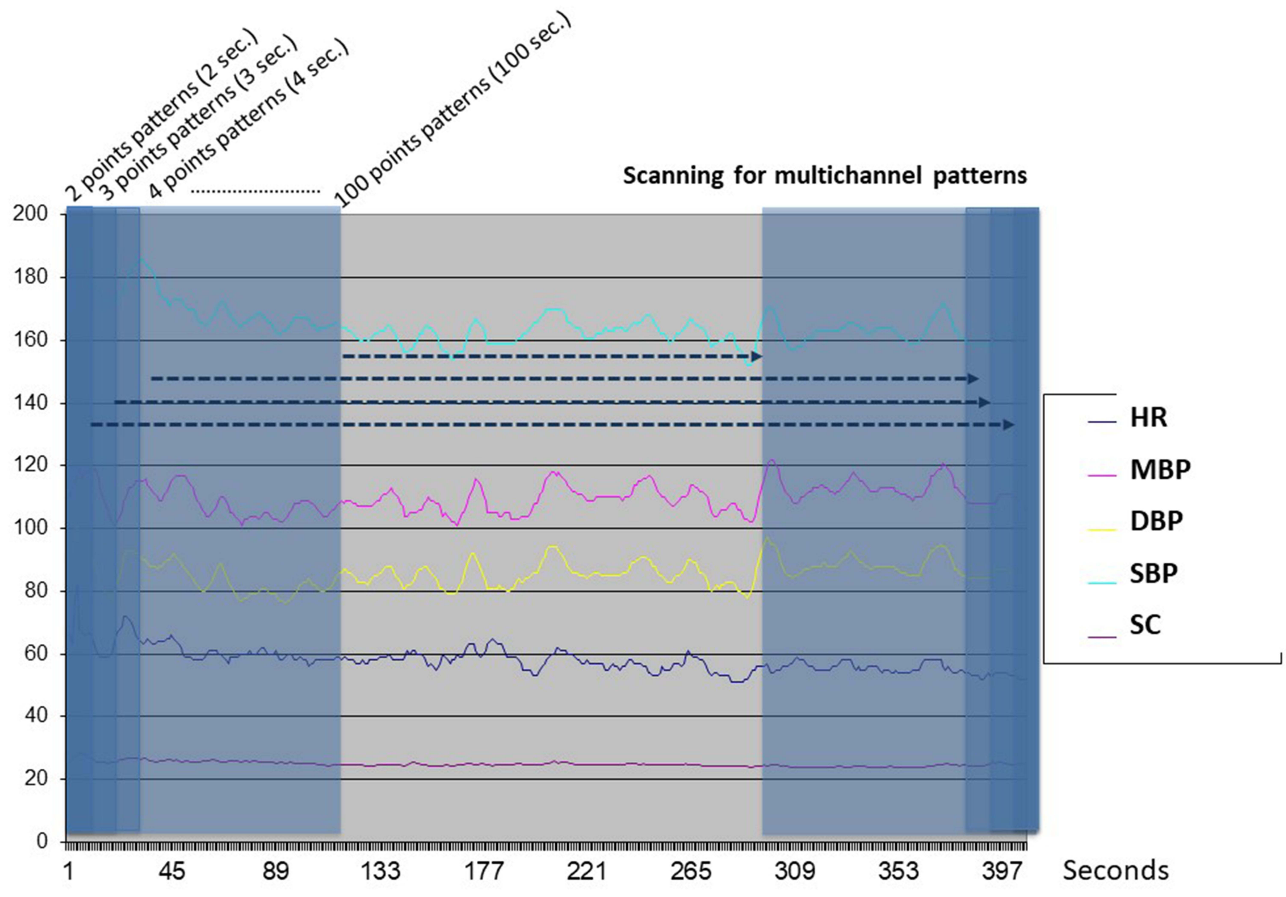

Figure 6 Graphic representation of machine-learning scanning process to detect multi-channel time-patterns predicting other time-patterns. A number of similar associated time-patterns is stored as analogs for forecasting purposes.
Abbreviations: HR, Heart Rate; MBP, Mean Blood Pressure; DBP, Diastolic Blood Pressure; SBP, Systolic Blood Pressure; SC, Skin Conductance.

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continuously feed the big database (always anonymized) of many individuals with different diseases to continuously improve the precision of the predictive comparisons with the ongoing individual patterns, and the accuracy of the probability of disease prognosis. The system may include KM apps for home-based, personalized, and interactive monitoring services with real-time updating information through available communication (smart cell phones, laptops, tablets, etc.), with synchronic and interoperable multi-channel information processing.

These software applications shall include inter-operable and synchronic applications for digital devices (such as smartphones, tablets, computers, etc.) to be used by patients, health practitioners (both in specialized and primary healthcare services), informal caregivers, and health managers. This tool is integrated into a TI-Health platform, with the information distributed in each agency using cloud computing technology, with different types of information access according to the needs of each agency and participant.

The software shall be installed in the user's digital device (computer, tablet, smartphone). A wireless SWT multi-sensor may be connected to the digital device regularly. Depth cameras (for analysis of body movements and postures) and smart speakers may be included for those patients with more difficulties in movement. Smart speakers allow patients to answer the daily questionnaire by voice after a reminder programmed into the smart speaker, which will administer the questions orally (using a dialog assistant). The oral information can be automatically processed and transcribed, containing a feedback interface that supports the user with bi-directional feedback on behavior, psychological measures, and physiological changes.

All this information from a large pool of patients may be clustered in a big database into a taxonomy of (genetic-physio-psycho-social) profiles. This clustering of patterns, algorithms, and bio-psycho-social indicators related to illnesses and health status compose the predictive analogs.

Approaching Data Protection

Data protection within a health governance system is a key concern to the Delphi experts in this study. Data may be connected during analysis to form the distributed big database (see Figure 7). In a federated "neural" big-data architecture, data remains stored on the servers and computers of the participant institutions and individuals gathering that information, connected via cloud computing technology only in the data analysis process. The distributed database may be formed of relational and NoSQL (Not-Only-Structured Query Language) database elements. In some cases, in terms of processing medical information, NoSQL databases are considered to be a favorable option.[39]

KM procedures may bring easy and comprehensive access to predictive information about needs and problems with any device, with interoperable, converged, synced, compatible, and integrative interfaces and access to encrypted fields from different servers through federated digital technology. The ability to constantly feed the databases with updated information in real-time in any digital device will allow distributed interoperability as a strategy for data protection with different access and confidentiality levels, shells, and filters based on each agency or service needs (see Figure 7). The strategy for data protection also includes data minimization and purpose limitation (only collecting and sharing data that is strictly necessary for the intended purpose), role-based access control (restricting access to data based on user roles), strong encryption protocols (eg AES-256 and TLS 1.3) to protect data during storage and transmission, data anonymization and pseudonymisation, managing patient consent, and creating data use agreements and governance policies.

Early Detection

The software shall be able to analyze changes in physiological indices in response to individual behavioral and contextual changes. These results will also be compared with previously processed information of the individual and with the big database of populations with different illnesses for more accurate and complete monitoring, prediction, anticipation, and prevention, leading to more effective diagnosis, early detection, and rapid response to health relapses or crises (see Figure 8). Early detection of the presence of an illnesses may be achieved through the machine-learning analysis of physiological time patterns (comparing populations with similar patterns and illness progress), without the patient needing to do anything as the system will automatically warn the person and the health center. The health system should also provide updates on positive bio-psycho-social elements of health protection against risk factors of impairments.

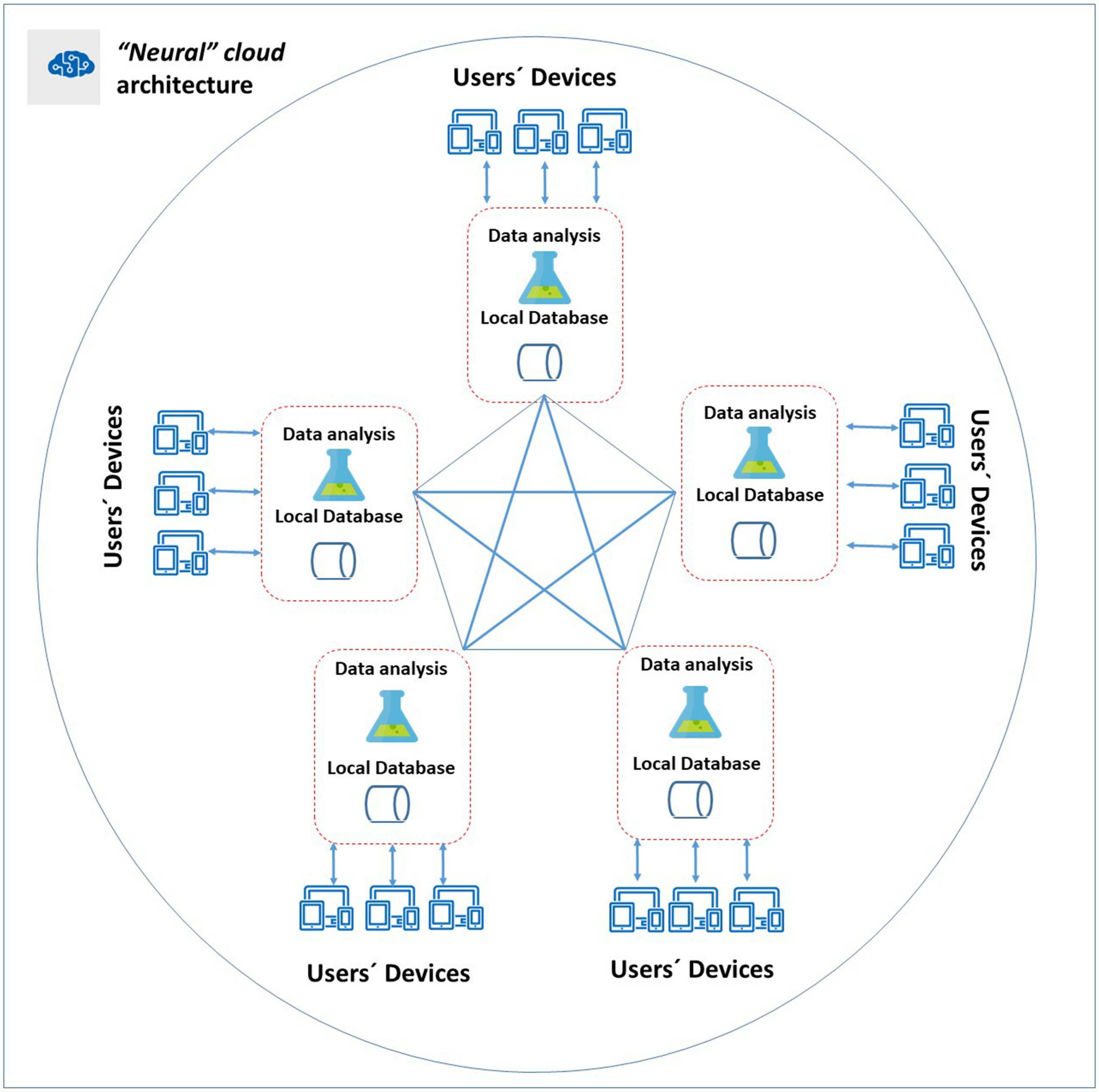

Figure 7 Federated big-data architecture of data processing.

Healthcare systems such as TI-Health may have the capacity to detect illnesses with a high degree of precision, including new epidemics such as the COVID-19 at population levels. Infectious illnesses have (like most diseases) their own physiological "fingerprints." Systems such as TI-Health might detect new "fingerprints" in populations before even the illness is detected in health centers. It may bring simple and fast monitoring of the outbreaks without the patients needing to leave their homes.

Healthcare Ecosystems

An open ecosystem approach to system development enables boosting value chains and networks for exploiting and scaling up the system while making possible its synergic integration with other digital health ecosystems. Most current eHealth ecosystems are built as soft, blurry network organizations that may fade away due to a lack of leading roles. Collaborative leadership in horizontal networks may make the ecosystems grow in effective and sustainable ways.

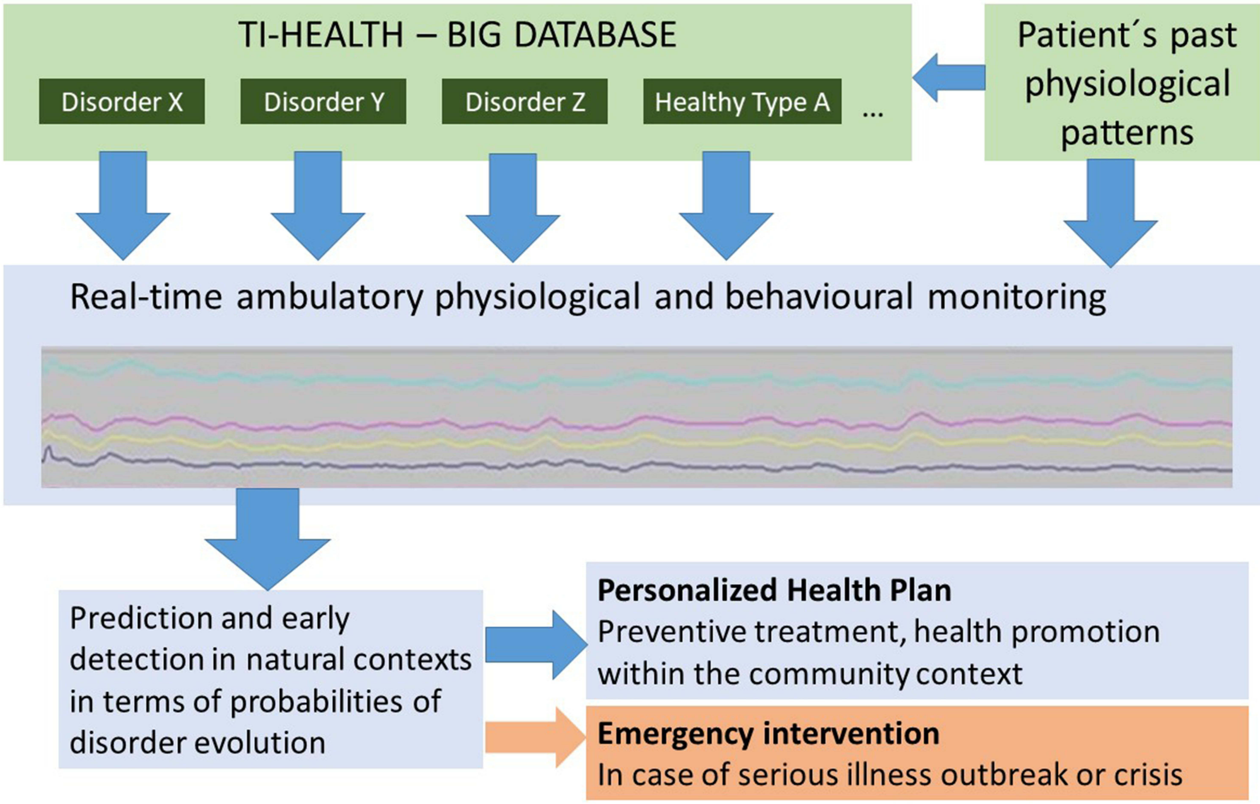

Figure 8 TI-Health prediction, early diagnosis, prevention and promotion process.

A healthcare ecosystem may deploy a cross-national governance system, including collaborative leading roles at local (with community health managers from participant health institutions) and cross-national levels (with data managers in charge of the international processing of data). Even though this system may be best useful for the aging patient, it could perfectly be scaled to any age group. This would provide more valuable data for higher precision on prediction and early detection.

System Assessment Within the Implementation Timeframe

System effectiveness will be evaluated based on changes in key health indicators that reflect clinical outcomes, cost-efficiency, and quality of life. These indicators include reductions in hospitalizations; preservation of autonomy, cognitive function, and functional capacity; improvements in self-monitoring ability, safety, and comfort; therapeutic effectiveness; treatment adherence; and the usability of in-home monitoring technologies. Simultaneously, the evaluation will identify barriers to system deployment, including issues related to service organization, data privacy, provider acceptance and training, system security and safety, and financial and economic sustainability.

Throughout the implementation phase, the system will undergo continuous evaluation, leveraging the automatic learning methodology and the active engagement of all stakeholders. Full implementation of the integrated healthcare system is expected to take approximately three years, with substantial improvements in patient health outcomes anticipated within the first year following initial deployment.

Conclusion and Implications for the Future of Healthcare

The current digital health trends are opening an exciting scene in predictive, preventive, and personalized clinical intervention and healthcare. In this work, a framework for the future of this field has been described by taking many of the most relevant elements of these trends and the experts' feedback on them into consideration. The final picture portrays a promising future with a significant advance in healthcare effectiveness, cost-efficiency, and quality of life.

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These integrative and home-based approaches to healthcare systems, as the one here described, may bring significant positive impacts at different levels:

(i) A complete health picture for epidemiological studies. Studying psycho-physiological time coordination patterns in various environmental and social contexts will provide a more comprehensive knowledge of all positive and negative health factors and their related dynamics predicting current and future individual health status. This approach provides further knowledge on the early detection of illnesses with high precision at particular levels and early detection of the outbreak of new epidemics at population levels, without the aging patients needing to leave their homes.

(ii) A systemic concept of diagnosis and clinical intervention in the aging patient. The described approach builds a diagnostic concept that includes all the main etiological, triggering, influencing, manifesting, and consequential factors of health and illness and the evolution of the relations among them. The healthcare system includes the patient's home and community and absolute time-based, dynamic, and integrated indices as a core approach, opening new scientific avenues.

(iii) A patient-centered and home-based approach. The healthcare approach described here is centered on the aging patient's environment and living conditions, which is the basis of PPM. A relationship management approach is fundamental in a healthcare system aimed at following and supporting the person's evolution for optimal quality of life. It stresses the need to consider the active participation of patients and caregivers in information gathering, analysis, and delivery, that is, in information co-production. This, in turn, will contribute to providing integrated care to the patient and support to those informal caregivers.

(iv) Towards fully inclusive and humane healthcare. New digital health tools must be helpful for closer, more personalized healthcare. These approaches facilitate the detection and face-to-face care of those most needed of attention through their predicting and knowledge-management tools, reaching and selecting those cases most needed for home-based care. This will enable healthcare tailored to the plurality of needs and problems impacting the health of our diverse society and contributing to guaranteeing the same rights to quality health to any social group. The TI-Health system is designed for seamless integration into existing healthcare infrastructures, with interoperability features that align with different current remote care platforms and electronic health records. It requires minimal training and resources, making it feasible for a range of settings—from primary care to community health networks. These attributes support its potential for scalable, sustainable adoption in real-world healthcare environments.

Ethical, Social, and Legal Challenges

Gathering data from humans brings some ethical challenges. Different measures may be taken to address these challenges, such as:

- Data protection. Ethical criteria shall enable information sharing and community participation while protecting personal information and confidentiality. Practitioners, patients, and informal caregivers shall have access only to the information they are entitled to and need to carry out their own activities. The ethical commissions shall previously approve all procedures of all health centers. All patients shall be requested informed consent for the use of data only for clinical purposes, guaranteeing confidentiality in data processing, always according to the national and international regulations on data protection.

- Inclusiveness. Ethical criteria shall be used to guarantee that healthcare reaches a diverse society, with principles of inclusiveness and extensiveness, preventing discrimination, biases, and invisibility due to gender, race, cultural background, origin, age, and beliefs.

Abbreviations

AI, artificial intelligence; ICT, information and communication technology; KM, knowledge management; NoSQL, not-only-structured query language; SWT, smart wearable technologies.

Data Sharing Statement

The raw data supporting the conclusions of this article will be made available by the authors upon request as appropriate.

Ethics Approval and Informed Consent

All participants provided informed consent before completing the questionnaire. Participation in the study was voluntary, guaranteeing confidentiality in data processing. The questionnaire stated a data protection guarantee submitted to the EU 2016/679 regulation of the European Parliament and Council on April 27th, 2016. The study followed ethical procedures by the Declaration of Helsinki[35] and had the approval of the Research Ethical Committee at the Complutense University of Madrid (Spain) (ref n° CE_20230511-08_SAL).

Consent for Publication

All authors confirm that all the details of the article can be published, and that the authors providing consent have been shown the article contents to be published.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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