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Review

Smart Solutions for Diet-Related Disease Management: Connected Care, Remote Health Monitoring Systems, and Integrated Insights for Advanced Evaluation

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Abstract: The prevalence of diet-related diseases underscores the imperative for innovative management approaches. The deployment of smart solutions signifies a paradigmatic evolution, capitalising on advanced technologies to enhance precision and efficacy. This paper aims to present and explore smart solutions for the management of diet-related diseases, focusing on leveraging advanced technologies, such as connected care, the Internet of Medical Things (IoMT), and remote health monitoring systems (RHMS), to address the rising prevalence of diet-related diseases. This transformative approach is exemplified in case studies focusing on tailored RHMS capabilities. This paper aims to showcase the potential of three RHMS in introducing a novel evaluation method and their customisation for proactive management of conditions influenced by dietary habits. The RO-SmartAgeing System uniquely addresses age-related aspects, providing an integrated approach that considers the long-term impact of dietary choices on ageing, marking an advanced perspective in healthcare. The NeuroPredict Platform, leveraging complex neuroinformatics, enhances the understanding of connections between brain health, nutrition, and overall well-being, contributing novel insights to healthcare assessments. Focused on liver health monitoring, the HepatoConect system delivers real-time data for personalized dietary recommendations, offering a distinctive approach to disease management. By integrating cutting-edge technologies, these smart solutions transcend traditional healthcare boundaries.

Keywords: remote health monitoring systems; integrated insights; advanced evaluation; liver cirrhosis; schizophrenia; tailored patient-centric approach

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1. Introduction

1.1. Background of Diet-Related Diseases

Diet-related diseases are a significant concern globally due to their prevalence and impact on public health. Several factors contribute to the rising incidence of these diseases, including changes in dietary habits, sedentary lifestyles, and socioeconomic influences. Some prevalent diet-related diseases are obesity, type 2 diabetes, cardiovascular diseases, certain cancers, osteoporosis, malnutrition, and mental health disorders. Here is an overview of them, as follows:

- *Obesity*: Obesity has reached epidemic proportions worldwide. It is linked to various health issues, like heart disease, type 2 diabetes, certain cancers, and musculoskeletal disorders [1]. Poor dietary choices, high caloric intake, and lack of physical activity contribute significantly to its prevalence.
- *Type 2 Diabetes*: often associated with obesity, type 2 diabetes occurs mainly as a result of insulin resistance or, in selected cases, inadequate pancreatic insulin secretion [2], and is heavily influenced by dietary patterns, particularly high sugar and refined carbohydrate consumption [3].
- *Cardiovascular Diseases*: Diet plays a pivotal role in cardiovascular health [4]. High intake of saturated and trans fats, excessive salt, and low intake of fruits, vegetables, and whole grains contribute to conditions like hypertension, coronary artery disease, and stroke.
- *Certain Cancers*: while genetics and environmental factors play a role, diets high in processed foods [5] and red meat and low in fruits, vegetables, and fibre are associated with increased cancer risk, particularly colorectal, breast, and prostate cancers.
- *Osteoporosis*: inadequate intake of calcium and vitamin D, often due to poor dietary choices or malnutrition, can contribute to osteoporosis [6], weakening bones and increasing fracture risk, especially in older adults.
- *Mental Health Disorders*: Emerging research suggests a link between diet and mental health [7]. Diets high in processed foods and sugars may contribute to increased risks of depression and anxiety [8], while diets rich in fruits, vegetables, and omega-3 fatty acids may have protective effects.
- *Malnutrition*: while obesity is a concern, malnutrition due to inadequate intake of essential nutrients is also prevalent in some populations, leading to deficiencies in micro- and macronutrients with a significant impact on overall health [9].

In 2001, chronic diseases accounted for approximately 60% of deaths worldwide, almost half of them being attributed to cardiovascular diseases. A 2019 study found that poor diet was responsible for more deaths globally than tobacco or any other health risk, accounting for one in every five deaths (i.e., 10.9 million deaths) (22% of all deaths among adults) in 2017, with cardiovascular disease as the leading cause, followed by cancer and diabetes. Poor diet also represented 16% of all disability-adjusted life years among adults globally, with Egypt having the highest rate of diet-related deaths in 2017, while Japan had the lowest, emphasising the role of nutritional habits. Although the composition and impact of individual dietary factors vary across nations, a low intake of fibre (i.e., whole grains), fruit, vegetables, nuts and seeds, and omega-3 fatty acids, as well as a high intake of sodium, especially from processed foods, accounted for more than 50% of diet-related deaths, while the remaining were attributed mainly to a high consumption of red meat, sugar-sweetened beverages, and trans fats [10]. Despite the overall medical progress, the World Health Organization, through its annual World Health Statistics Report of 2023, predicted that according to the present trend, by approximately 2050 chronic diet-related diseases, such as cardiovascular disease, cancer, and diabetes, will account for 86% of the 90 million deaths each year, a staggering 90% increase in absolute numbers since 2019 [11].

LC is a chronic liver condition resulting from prolonged liver injury secondary to viral hepatitis, alcohol abuse, and metabolic dysfunction. Drug-induced liver injury, monogenic diseases (hemochromatosis, Wilson disease, alpha-1-antitrypsin deficiency, lysosomal acid lipase deficiency, familial hypercholesterolemia, and other inborn errors of metabolism), and miscellaneous or idiopathic causes account for only a minority of cases.

Since the implementation of universal hepatitis B vaccination and the development of highly effective antiviral treatment against hepatitis C infection, we are witnessing an alarming surge in the global incidence of liver cirrhosis (LC) caused by metabolic dysfunction-associated steatotic liver disease (MASLD), a new terminology recently introduced by the American and European Associations for the Study of Liver Diseases [12]. While in developing countries viral hepatitis and alcohol abuse still account for a significant proportion of LC cases, MASLD, as a predominantly diet-related disease, has rapidly

become the most common cause of chronic liver impairment, affecting more than 30% of the global population. Although it was considered to be more prevalent in countries with high standards of living, metabolic syndrome, as the main cause of MASLD, has registered an overall dramatic surge in incidence, as a result of remarkable changes in lifestyle, diet, and globalisation. A recent study analysing the incidence trends of LC caused by metabolic dysfunction-associated steatohepatitis (MASH), formerly nonalcoholic steatohepatitis (NASH), found an alarming increase in incidence of about 105.56% globally between 1990 and 2017 [13]. Along with the rising epidemic of obesity, MASLD/MASH might soon replace viral hepatitis as the most important aetiology of LC, causing an unimaginable clinical and economic burden. Comorbidities of MASLD, like obesity, type 2 diabetes mellitus, hyperlipidaemia, and cardiovascular disease (hypertension, atherosclerosis, ischemic heart disease, etc.), are diet-related risk factors that significantly contribute to the progression of liver impairment. Approximately 20–50% of MASLD patients will suffer from LC within 10 years [14], as a result of an annual rate of fibrosis progression of more than 40%, with an incidence of advanced fibrosis of 67.9 in 1000 person-years [15]. In addition to MASLD, alcohol use disorder is an important risk factor for alcohol-associated liver disease (ALD), significantly contributing to malnutrition and micronutrient deficiencies in patients with LC. Alterations in nutrient metabolism are common in chronic alcohol use and may contribute to alcohol-induced organ injury [16]. Experimental data have demonstrated that alcohol-mediated variation in the composition of the gut microbiome results in the disruption of intestinal barrier integrity, increased gut permeability, and endotoxemia, which further causes liver injury and significantly increases the risk of decompensating events [17]. Therefore, personalized dietary interventions and adequate nutritional supplementation may prevent the development of alcohol-induced organ injury.

By extrapolating the diet–health relationship, the latest evidence focusing on the diversity and impact of intestinal microbiota on developing chronic diseases suggests the fact that dietary habits have a strong influence starting from early life, as improvements in the nutritional status of women before conception, during pregnancy and breastfeeding will have favourable outcomes regarding foetal growth, survival, and better long-term health [18]. Recent studies have shown that human milk microbiota plays a crucial role in shaping children's health, as it almost exclusively contributes to microbial gastrointestinal colonisation in the first 100 days of life. Suboptimal maternal diet and high body mass index are some of the several factors that influence the diversity and composition of breast milk microbiota, and intestinal microbial dysbiosis in children is a trigger for the later onset of chronic diseases such as obesity [19]. Mounting evidence also suggests that there is a link between intestinal dysbiosis, microbial diversity, and psychiatric disorders like schizophrenia, with a potential for therapeutic implications through microbiome manipulation and prebiotics supplementation in the form of nonfermentable fibre. A poor diet later in life may negatively impact microbial diversity and act as a modifiable risk factor for mental diseases and many others [20]. Schizophrenia, a multifaceted psychiatric disorder characterized by disturbances in thought processes, perceptions, and emotions, stands as a profound challenge to both mental and physical well-being. The intricate interplay between schizophrenia, dietary habits, and physical health has emerged as a critical area of exploration, shedding light on the far-reaching consequences of this disorder. Beyond the traditionally recognized mental health implications, schizophrenia intricately weaves its impact into the fabric of one's overall health, extending its reach to encompass physiological realms.

Taking into consideration the abovementioned aspects regarding the role of optimising nutrition in all stages of life, there is an urgent need to globally increase the level of education with a focus on promoting the intake of healthy nutrients, rather than only targeting bad nutritional habits like sugar and fat consumption. While low educational levels, in general, are related to poor nutrition choices, like diets high in carbohydrates, sweets, and red meats and low in fibres, high educational levels promote increased nutritional

diversity and a lower caloric intake [21] and appear to have a mitigating effect on poor diet in low-income countries [22].

Personalized nutrition strategies use individual-specific information to promote dietary behaviour change that may result in health benefits. The outcomes of providing nutrition education could be summarised into two main aspects, both of them being measurable:

- *Promoting nutritional behaviour change* is an essential step resulting from proper information about (but not limited to) dietary choices, aiming to promote measurable changes in dietary behaviours that may result in health improvement. The key element to consider is choosing adequate individual-specific information and ensuring sustainability and long-term adherence to new diet and lifestyle patterns. Current tools used to measure nutritional behaviour can be broadly classified as either active (requiring user input) or passive (not requiring user input). Recent advancements in technology have significantly impacted the use of passive tools for assessing dietary intake [23], eating behaviour, and physical activity [24], which encompass various engineered devices, like wearables and sensors, as well as mobile phone applications and web-based tools. One area of promise in the field of emerging tools is sensor technology, which aims to facilitate more precise and unbiased measurement of dietary intake and eating behaviour compared to self-report methods and, therefore, may improve long-term adherence. These sensor-based tools can generally be categorized into three groups: wearable sensors, camera-based devices, and weight scale-based devices. Wearable sensors include devices with sensors positioned on the head or neck to detect chewing or swallowing, inertial sensors on the wrist to detect hand-to-mouth gestures as a proxy for bites, and other similar devices. Camera-based methods employ food images to identify consumed food and estimate energy intake [25].
- *Providing measurable health benefits*, which must be assessed using validated methodologies and metrics. Examples of quantifiable validated indicators of well-being encompass alterations in a particular nutrient biomarker (for instance, enhancing micronutrient levels), weight and body composition enhancements (such as improving weight status, bone mineral density, and muscle mass), or measurements of blood glucose regulation (for example, ameliorated fasting glucose or haemoglobin A1c), serum lipid profile, or protein function status and synthesis [26].

The delivery of nutrition care has undergone significant changes, primarily as a result of the initiatives associated with the COVID-19 pandemic, which have sparked extensive and comprehensive transformation within the healthcare industry. Telehealth-delivered dietary interventions incorporating nutrition education and teleconsultations with dieticians (including nutritional assessment, management plans, and follow-up) have emerged as a new tool implemented during the COVID-19 pandemic as an alternative to in-person visits [27], and they have proven to be an effective approach to improve dietary behaviours among adults with chronic health conditions [28]. Apart from telehealth-enabled nutritional interventions, highly accessible nutrition programs, including culturally appropriate dietary recommendations that are tailored for low economic resources and alternative telenutrition approaches through social/mass media, which surged during the COVID-19 pandemic, could assist in managing diet-related chronic diseases globally and serve as a support for developing a global strategy to combat the growing burden of chronic diseases [29].

A recent systematic review of randomized clinical trials evaluating the cost-effectiveness of telehealth nutritional interventions in adults with chronic disease found that mHealth nutrition interventions were the most cost-effective (60%), across all telehealth interventions [30], reasoning that future mHealth-based interventions for managing the increasing number of patients at risk of or already diagnosed with chronic diet-related diseases would be a justifiable approach. However, patient demand and acceptance have a pivotal role in the successful implementation of telehealth in clinical care. To depict the future of telehealth in the post-COVID-19 era, the US Medical Group Management Association created a poll to determine the shift in patients' demand for telehealth; discouragingly, nearly two-thirds

(64%) of doctors reported that patient demand had decreased from the beginning of 2023 (compared to 28% in November 2022), while 22% reported a constant demand, and 14% reported increased demand [31]. We consider that future research is needed to evaluate this trend over time, as factors like prolonged isolation and anxiety may have determined patients to rather seek in-person visits during the immediate postpandemic period.

We further highlighted some examples of retained and expanded use of telehealth, some of them incorporating tools for lifestyle change and diet management:

DarioHealth [32] is an all-encompassing digital system tailored for diabetes management. The platform features a smartphone application that monitors glucose levels, offers valuable insights into dietary decisions, and aids healthcare professionals in refining treatment strategies. *Dario* is currently investigating correlations among concurrent health conditions to enhance care protocols. For instance, recent studies involving *Dario* users managing both diabetes and hypertension indicate potential links between blood pressure reduction and blood glucose reduction. Additionally, findings suggest that educating individuals about comorbidities can inspire the adoption of healthier behaviours overall.

Cirrhosis Care by Seqster [33] is designed to facilitate the remote monitoring and supervision of liver cirrhosis. It offers current and evidence-based materials to aid in the management of cirrhosis, featuring specialized functionalities intended for healthcare professionals. Essential resources within the platform furnish details on the primary complications associated with cirrhosis, self-management recommendations, and indicators of potential issues.

Biofourmis [34] provides solutions for remote patient monitoring across diverse medical conditions. The company delivers connected, customizable, and individualized care choices for the management of patients, whether in virtual or in-person settings. By leveraging dynamic care pathways, continuous monitoring, coordination tools, and adaptable services, *Biofourmis* empowers clinicians to administer hospital-level care within the comfort of a patient's home. The predictive analytics embedded in the solution offer real-time, personalized data and alerts to clinicians, enabling the early detection of potential clinical deterioration. This proactive approach enhances patient safety, improves outcomes, and contributes to cost savings. Additionally, *Biofourmis* supports a wide array of monitoring options through clinically validated devices, ensuring continuous and reliable data collection.

CirrhoCare® [35] is a smartphone-enabled remote monitoring system developed and coordinated by the University College London Division of Medicine and Royal Free Hospital, London, designed for the management of patients with advanced liver cirrhosis. *CirrhoCare*® encompasses a patient-oriented application connected to smart devices specifically intended to monitor early signs and symptoms of complications like ascites, renal impairment, and hepatic encephalopathy but also to provide educational strategies. This system empowers medical professionals to remotely oversee patients' well-being, thereby facilitating prompt responses in the event of complications. A pilot study assessing the feasibility and potential clinical benefits of *CirrhoCare*® comparing 20 liver cirrhosis patients receiving the telemonitoring intervention to 20 controls demonstrated significant benefits in terms of reduced hospital readmissions and need for outpatient interventions [36], and a new randomized controlled trial involving more than 200 patients will be conducted to set the stage for large-scale implementation of the telemonitoring system.

Seeds of Hope [37] features an online telehealth program offering extended postpandemic teletherapy sessions for the treatment of eating disorders. It offers clinicians the ability to monitor patients' symptoms more consistently and increases patient adherence while reducing the costs of care.

Addressing diet-related diseases often involves multifaceted approaches, including public health interventions and education on healthy eating habits, policy changes, and individual lifestyle modifications. Governments, healthcare providers, communities, and individuals all play an important role in combating these diseases by promoting better nutrition and healthier lifestyles.

This paper aims to present how comprehensive integrated monitoring for diet-related disease management and other targeted capabilities provided by RHMS, as customizable smart solutions, can be perceived and represent a novel evaluation method.

1.2. Analysis of the Problem of Disease Management

Disease management refers to a coordinated and comprehensive approach to healthcare that focuses on preventing and managing chronic illnesses or conditions. It includes strategies for enhancing the quality of life and health of individuals afflicted by various illnesses.

Using experimental or randomized controlled trials (RCTs) is an important way to strengthen the body of evidence supporting disease management, especially when it comes to disorders linked to nutrition. These trials are useful resources for examining therapies meant to prevent or treat long-term diseases or ailments that have a close relationship to food habits. When it comes to diet-related disorders, such as obesity, diabetes, and cardiovascular conditions, randomized controlled trials (RCTs) provide a methodical way to thoroughly assess how dietary changes or particular nutritional therapies affect health outcomes. These trials provide stronger and more trustworthy data to direct therapies that address the complexities of diet-associated chronic diseases by allowing researchers to identify causal linkages through the use of randomisation and control groups. In the field of nutrition and diet-related health, this evidence, in turn, influences healthcare practices and policy decisions, leading to more successful approaches to disease prevention and management.

This approach encompasses various elements, such as the following:

- *Prevention*: disease management emphasizes preventive measures to reduce the risk of developing chronic conditions through lifestyle modifications, screenings, vaccinations, and education [38–40].
- Early detection: timely identification and diagnosis of diseases enable healthcare providers to intervene early, potentially preventing complications and improving treatment outcomes [41,42].
- Treatment and care: disease management involves the provision of appropriate medical care, medications, therapies, and interventions tailored to the specific needs of individuals with chronic illnesses [43,44].
- Patient education and empowerment: this includes educating patients about their conditions, empowering them to actively participate in their care, and promoting self-management techniques to improve adherence to treatment plans and lifestyle modifications [45].
- Care coordination: disease management often involves a multidisciplinary approach, with healthcare professionals collaborating to provide integrated and coordinated care, ensuring that patients receive comprehensive support [46,47].
- Monitoring and follow-up: continuous monitoring of patients' health status, regular follow-up visits, and the use of technology for remote monitoring [48,49] contribute to effective disease management by tracking progress and making necessary adjustments to treatment plans.

Overall, disease management aims to optimize the health and well-being of individuals with chronic conditions by emphasising prevention, early intervention, patient education, and coordinated care to improve their overall quality of life.

The delivery of healthcare could be completely transformed by integrating AI-based tools and massive language models into care management. These technologies can improve administrative work efficiency, clinical decision-making efficiency, and patient involvement through the use of sophisticated machine learning algorithms and natural language processing (NLP). Big language models make it possible to glean insightful information from unstructured healthcare data, leading to more precise and thorough patient records. Consequently, this leads to enhanced clinical decision support systems, assisting medical practitioners in reaching evidence-based conclusions. Furthermore, AI-powered chatbots and virtual assistants may converse naturally with patients, offering individualized health

information, responding to inquiries, and providing support—all of which can improve patient education and treatment plan adherence.

Predictive analytics is another area where AI has the potential to improve care management by allowing the detection of patterns that may indicate future health hazards [50]. In the end, this prevents complications and enhances patient outcomes by enabling early interventions and individualized treatment regimens. AI-powered remote monitoring enables continuous data analysis from wearables, facilitating the early identification of minute changes in health. Healthcare personnel are freed up to concentrate more on providing direct patient care by using AI to automate repetitive administrative activities like appointment scheduling and billing. Large language models and AI-based technologies can improve efficiency and accuracy in care management, but they also have the ability to change the way healthcare is delivered by making it more patient-centred, proactive, and data-driven.

Innovative approaches in disease management are crucial for several reasons:

- ***Improved outcomes***: *(a) Precision medicine* provides tailored treatments based on an individual's genetics, environment, and lifestyle, which can lead to more effective and personalized therapies, improving patient outcomes [51]; *(b) advanced and innovative technologies* like AI, telemedicine, wearable devices, and robotics enable remote monitoring, early detection, and personalized care and lead to better disease management [52];
- ***Cost-efficiency***: *(a) preventive focus* is often emphasized by the innovative approaches and preventive measures leading to reductions in the financial burden on healthcare systems [53] or the diagnosis of chronic diseases in early stages when treatments are more manageable and less costly; *(b) streamlined processes* through technology can reduce administrative costs and errors in healthcare delivery.
- ***Accessibility and equity***: *(a) Telemedicine and remote monitoring* bridge geographical gaps, providing access to healthcare for remote or underserved populations and increasing the accessibility to healthcare services [54]; *(b) affordability and scalability* of the solutions that make treatments accessible to a larger number of people. Ensuring scalability without significant disruptions requires developing systems that are simple to integrate and communicate across several platforms [55].
- ***Data-driven insights***: *(a) Big data analytics* is used for analysing huge amounts of healthcare data and can reveal patterns, improve diagnostics, and assist in predicting disease outbreaks or trends [56]. Big data applications in the medical field enhance medical care's quality and optimize medical procedures and management techniques [57]; *(b) real-time decision making* involves improved preventative treatment, and early interventions are made possible by the real-time monitoring of certain health parameters that are regularly and continuously collected. Rapid analysis of real-time data helps healthcare providers make quicker, more informed decisions, improving patient care. Real-time data may easily flow into algorithms built to analyse, understand, and extract actionable insights thanks to real-time monitoring features integrated with decision-support algorithms. With the help of this connection, decision makers will always have access to up-to-date data that have been carefully analysed.
- ***Patient-centred care***: *(a) Empowerment and engagement* of patients to actively participate in their healthcare decisions, fostering better adherence to treatment plans and lifestyle changes, are promoted using innovative tools and approaches. Healthcare professionals can create a cooperative atmosphere in which patients feel empowered, knowledgeable, and actively involved in their own health management by adopting the concept of patient-centred care [58]. *(b) Improved Communication* between doctor and patient using telehealth platforms and communication tools has the role of enhancing their interactions, *ensuring* better understanding and compliance with treatment protocols.
- ***Research and development***: *(a) accelerated discovery* of new treatments, drugs, and therapies due to innovations in research, potentially leading to breakthroughs in disease

management; *(b) collaboration* among researchers and healthcare professionals globally fosters collaboration, accelerating the pace of discoveries and advancements [59].

- ***Behavioural change and adherence***: *(a) encouraging patients to follow their treatment regimens* and take up better lifestyles through the use of motivating techniques like gamification; *(b) better illness management results* can be obtained from people being motivated to make beneficial behavioural changes by personalized feedback provided by digital health platforms [60].
- ***Education and awareness***: *Patients* who are better informed about the necessity of managing their diseases and who have access to educational materials *are more proactive in their pursuit of health* [61].
- ***Community support and peer interaction***: *Social components added to healthcare applications or platforms* can help patients with comparable diseases feel more connected to one another. Shared experiences and peer support can be effective sources of motivation [62].
- ***Self-monitoring and goal setting***: *Motivation can be increased by using interactive tools* that let patients create and monitor individual health goals. Monitoring progress and acknowledging accomplishments create a positive feedback loop that promotes ongoing participation [63].
- ***Feedback and positive reinforcement***: Encouraging patients to adhere to their health management regimens by giving them constructive, real-time feedback on their health measurements or accomplishments [60].
- ***Integration of mental health support***: It is critical to *address the psychological and emotional components of managing a condition.* Including mental health services, such as virtual therapy or mindfulness applications, can encourage people to manage their illness more skilfully [64].
- ***Personalized health coaching***: *AI-driven personalized recommendations* can give patients individualized advice and inspiration based on their particular requirements and advancement [65].
- ***Patient-reported outcomes (PROs)***: Incorporating patient-reported outcomes into illness management strategies and having *patients actively participate in their healthcare plans* can have a good effect on motivation [66].

Novel strategies for managing diseases establish a more comprehensive and patient-focused environment, encouraging sustained involvement and favourable health consequences. These strategies have the potential to revolutionize healthcare systems, enhance patient outcomes, boost accessibility, reduce expenses, and eventually contribute to a healthier global population.

Innovative approaches in disease management hold the promise of transforming healthcare systems, improving patient outcomes, increasing accessibility, and driving down costs, ultimately, leading to a healthier population worldwide.

1.3. Possible Innovative Solutions Related to the Problem of Disease Management

In the rapidly evolving field of healthcare, technology is essential to changing the way that conventional patient care approaches are implemented. Driven by technological advancements like remote health monitoring systems (RHMS) and the Internet of Medical Things (IoMT), connected care has become a dynamic paradigm that is reshaping the way healthcare is delivered in the future. In addition to making proactive, individualized patient care easier, this technological integration creates new assessment and evaluation issues. The exploration of connected care, IoMT, and RHMS reveals that the conventional frameworks for assessing healthcare treatments might require expansion. The growing range of technological applications in healthcare demands the creation of innovative assessment techniques that can fully reflect the complex effects of these advancements on patient care.

- ***Connected care*** refers to the application of digital technology to enhance patient communication, healthcare services, information systems, and care delivery to streamline

processes and to enable better access to healthcare services, especially for remote or underserved populations. Among other digital health solutions, it involves various tools like telemedicine, wearable devices, remote monitoring systems, electronic health records (EHRs), portals, and mobile health applications [67]. By enabling constant information exchange between patients, healthcare providers, and other stakeholders, connected care aims to enhance individualized medicine, provide real-time health monitoring, and encourage preventive care. To improve the coordination of health services, traditional healthcare systems are being changed to become more patient-centred, affordable, and accessible [68].

- ***Internet of Medical Things (IoMT)*** refers to the interconnectedness of medical devices, software programs, and medical systems through the Internet. It involves devices such as wearables, sensors, medical imaging equipment, and other monitoring tools that collect, transfer, and share data without human intervention. IoMT enables real-time monitoring, data analysis, and decision making, enhancing diagnostic capabilities, treatment effectiveness, and patient outcomes. The primary features of IoMT are as follows: *connectivity* (ability of devices to use the Internet to communicate with one another), *sensing* (ability of many IoMT-based devices to collect a variety of health data), *interactivity* (ability for two-way communication between the device and the patient or healthcare professionals; this can include alerting the patient to specific health issues, making recommendations, or allowing the healthcare provider to manage the device's settings), *automation* (ability for some tasks to be carried out automatically in response to specific criteria or conditions, like medicine administration, altering treatment parameters), *data processing and storage* (generation of vast amounts of data, necessitating their ability to be stored and processed; some IoMT-based devices handle this internally, while others rely on cloud-based processing and storage), *interoperability* (capacity to connect and operate with other devices, systems, or networks), *adaptability* (IoMT-based devices are often designed to be responsive to changing requirements and conditions; this may involve software upgrades that incorporate novel capabilities or enhancements, as well as the ability to adjust parameters based on the patient's health), *smart capabilities* (IoMT-based devices increasingly rely on artificial intelligence (AI) to process data and make complex decisions; this can involve identifying patterns, forecasting medical emergencies, or customising treatment plans), and *user-friendly interfaces* (due to their patient-friendly design, which takes into account the vast spectrum of users, including healthcare workers, patients, and people with varying levels of IT literacy) [69].
- ***Remote health monitoring systems (RHMS)*** encompass the technologies and systems used for remote monitoring of patients' health metrics. These systems often utilize IoMT devices to collect data on vital signs, medication adherence, activity levels, and other health-related information. RHMS allow healthcare providers to remotely track patients' health statuses, intervene if necessary, and make informed decisions about their care. These systems employ cutting-edge technology to collect and safely transmit real-time health data, enabling medical professionals to make decisions about residents' health, respond quickly to issues, and provide individualized care based on thorough knowledge gained from analysing and processing health data.

Large-scale evidence of RHMS' enormous development and commercialisation potential was provided by the COVID-19 pandemic. They use their influence to increase access to medical care for a greater number of patients and offer insightful data for the patient profile that is updated regularly, contributing to medical research and development.

Particularly for older and physically challenged patients, these devices hold a lot of potential [70]. In open or closed situations, several wearable sensors or health-monitoring sensors, including blood pressure, oxygen, pulse, and heart rate sensors, are utilized in RHMS to observe patients [71]. The caregiver or physician is alerted to any anomaly in the patient's behaviour, allowing them to take immediate action. Sensors based on computer vision techniques are also employed to monitor patients' health.

- ***Demand for novel evaluation methods*** has grown with the fast progress in IoMT, RHMS, and connected care, alongside the management of diet-related diseases. Novel evaluation methods that take advantage of the cutting-edge features made possible by connected care, IoMT, and RHMS are required to meet this prerequisite. These methods combine advanced data analysis, predictive modelling, and real-time monitoring to provide a more thorough comprehension of patients' health conditions and outcomes, as well as an in-depth awareness of their dietary habits and overall state of health. By merging these technologies, healthcare professionals can obtain a wide range of data from different sources, giving them the ability to use cutting-edge methods to evaluate the effectiveness of interventions and treatment plans. These advanced evaluation methods not only enhance the precision of treatment strategies but also foster a proactive approach, allowing for timely adjustments to dietary recommendations and interventions. These progressive methods of evaluation not only improve the accuracy of therapeutic strategies but also support proactivity, enabling prompt adjustments to dietary recommendations and therapies.

The main objective of our paper is to present three RHMS that have been designed and developed by the authors of the paper, as well as how they can be customized for proactive management of conditions in which dietary habits influence both the disease progression and the treatment. Our three RHMS—RO-SmartAgeing System, NeuroPredict Platform, and HepatoConect System—provide innovative and adaptive capabilities, transforming customized diet-related disease management. This novel convergence of medical and IT domains not only improves comprehensive monitoring but also adds new aspects to the delivery of healthcare. The RO-SmartAgeing System distinctively addresses age-related aspects, offering an integrated approach to tailored solutions that take into account the long-term influence of dietary choices on ageing—an advanced perspective in healthcare. The NeuroPredict Platform, which uses complex neuroinformatics, provides a better knowledge of the multifaceted connections between brain health, nutrition, and general well-being, providing new insights into healthcare evaluations. The HepatoConect system, which focuses on liver health monitoring, offers real-time data for tailored dietary recommendations and optimizes disease management in a distinctive manner. By integrating cutting-edge technologies, such as smart devices, data analytics, and machine learning, with the intricacies of patient care and disease management, RHMS emerge as powerful tools that surpass traditional healthcare limitations. This collaborative approach establishes RHMS as innovative solutions in comprehensive healthcare administration, providing advanced technical solutions that go beyond simple monitoring to address a wider range of patient well-being, treatment effectiveness, and proactive health interventions.

2. Methods Used for Integrated Monitoring and Management of Diet-Related Diseases

2.1. RHMS-Based Novel Evaluation Method for Diet-Related Disease Management

Within the field of modern medicine, the fusion of IT and health sciences has resulted in novel approaches for managing diet-related diseases. Therefore, *integrated monitoring for diet-related disease management can be perceived as a novel evaluation method*.

Managing disorders that have a direct correlation to dietary habits comes with its own set of difficulties and factors to consider. The following are some of the ***key characteristics of diseases related to diet management***, exploring the intricate details that necessitate specific approaches for successful intervention and long-term health outcomes:

- ***Individualized dietary profiles***: The intrinsic diversity of individual diets is one of the key distinctions in the management of diet-related diseases. In contrast to standard treatment protocols, many disorders require a customized awareness of dietary practices among individuals [72]. Individual eating patterns are greatly influenced by a variety of factors, including personal preferences, social level, and cultural preferences. Differences in dietary profiles are not limited to differences in nutritional intake; they also take into account the larger sociocultural environment in which dietary choices are made. Cultural preferences influence dietary preferences and

eating habits in addition to determining what kind of foods people eat. Disparities become even greater by socioeconomic status, which influences dietary habits, as well as access to particular foods. Healthcare professionals may strengthen their patient–provider relationship and encourage commitment to dietary guidelines by adopting this individualized approach;

- ***Behavioural components and compliance***: Compliance with prescribed dietary changes by patients is a crucial aspect that impacts the effectiveness of therapies pertaining to behavioural components. Commitment levels are greatly impacted by elements including psychological challenges, social support networks, and motivation [73]. As a result, a successful management approach has to include behavioural psychology concepts, using strong support solutions, such as RHMS, and motivating strategies to increase a patient's commitment to dietary recommendations;
- ***Real-time monitoring and feedback***: Real-time monitoring is essential for managing diet-related diseases, because dietary habits are dynamic. In contrast with successful treatment programs, many diseases need ongoing evaluation and modification. Modern technologies allow for the continuous monitoring of eating habits through wearables and smartphone apps [74], which allows healthcare professionals to put measures in place quickly in response to new patterns. Including a feedback loop in the management process guarantees that interventions are flexible and adapted to patients' changing dietary requirements;
- ***Dynamic assessment of dietary habits***: The ability to dynamically analyse and understand the subtle aspects of individual dietary habits is fundamental to real-time monitoring. Conventional methods that depend on periodic assessments are unable to accurately reflect the daily fluctuations in food preferences. Technologies for real-time monitoring provide a detailed perspective [75], enabling healthcare professionals to monitor not just what patients eat but also when and how much they eat. This real-time nature establishes the foundation for a contextualized and more accurate knowledge of dietary behaviours, allowing for targeted and timely interventions;
- ***Nutritional education and empowerment***: The essential requirement for better diet-related disease management in the digital health domain is patient empowerment via targeted nutrition education. Making educated decisions is encouraged when patients have an in-depth understanding of how their food choices affect their health [76]. Personal counselling and RHMS that provide easily available and tailored dietary guidance are examples of educational approaches. Patients who feel empowered are more likely to take an active role in their own care, which improves long-term outcomes;
- ***Personalized digital interventions***: Educational interventions are carefully designed for the digital health field, taking into account the technological advances in healthcare [77,78]. Personalized consultations that make use of AI and personalized algorithms combine easily with RHMS. These solutions, which include web-based interfaces, mobile applications, and virtual learning environments, enable data-driven customisation in addition to accessibility. The efficacy of diet-related disease management is improved in this digitally augmented environment when patients receive personalized nutritional information that corresponds to their individual health profiles;
- ***Interdisciplinary collaboration***: Diseases linked to diet may arise from an intricate relationship between environmental, psychological, and physiological variables [79]. Thus, multidisciplinary cooperation is necessary for successful management. To develop comprehensive management plans, psychologists, IT professionals, nutritionists, and healthcare professionals have to collaborate adequately together. Because diet-related disorders are complex, a collaborative approach guarantees a thorough grasp of the patient's medical condition and enables balanced procedures.

Precision in data needs smart technologies for enhanced monitoring. *Precision data* are defined as highly precise, reliable, and consistent data [80]. In this sense, precision refers

to a high degree of reliability and accuracy in the information gathered. Precision data offer a comprehensive and precise picture of the information being measured or identified while also considering other pertinent factors. They eliminate the possibility of errors and uncertainties to the maximum extent feasible. Precision is essential for data collection and analysis in scientific and technological contexts, because it enhances the validity and reliability of research findings.

Precision data in the context of RHMS may include precise assessments of dietary intake, health parameters, or additional relevant variables.

The setting up of a smart monitoring environment, which is intended to guarantee the highest level of precision and dependability of data, is a fundamental component of the suggested innovative evaluation approach, namely, integrated monitoring for diet-related management. By using modern sensors and complex algorithms, the RHMS lowers data collecting errors. Using advanced analytics, the proposed evaluation method goes beyond traditional approaches. The assessment framework's integration of predictive modelling and identifying anomalies adds a dynamic and adaptable component to disease management. This approach provides itself as a proactive, data-driven framework that outperforms traditional ones, delivering increased efficacy in healthcare by predicting trends and finding abnormalities in real time.

Measurements of health parameters and dietary evaluations are made more accurate by machine learning algorithms that have been trained on a variety of datasets. These algorithms improve the accuracy of dietary assessments and health parameter measurements, and they form a core component of the smart monitoring environment. Machine learning algorithms can adjust to the peculiarities of each patient, leading to a degree of customisation and precision that is not possible with conventional methods.

The comprehensive monitoring provided by RHMS goes beyond conventional metrics and provides a holistic understanding and integrated insights for advanced evaluation. The proposed novel evaluation method goes beyond traditional measurements in the pursuit of accuracy in diet-related disease management inside the digital health domain, adopting the concept of comprehensive monitoring. Comprehensive monitoring encompasses environmental impacts, psychological aspects, and dietary intake in recognition of the complex characteristics of these illnesses. As it sets the framework for the next phase in digital health research, this careful integration of various sources of information attempts to reveal the intricate relationship between lifestyle, psychological well-being, and health outcomes.

The incorporation of psychological aspects into the assessment framework is one of the distinguishing characteristics of the comprehensive monitoring method. Understanding that psychological wellness has a significant influence on dietary habits and health outcomes, advanced analyses that explore mental health, stress, and emotional triggers are included in the integrated monitoring that is being proposed for diet-related disease management. Comprehending the psychological aspects helps to improve the understanding of the behavioural elements of diet-related disorders, which opens the door to more specialized and successful therapies.

Comprehensive monitoring widens its scope to include environmental factors that are critical in determining eating habits and health outcomes [81]. The proposed evaluation method incorporates external issues such as socioeconomic determinants, environmental stressors, and availability of healthy food choices in addition to individual actions. By attempting to determine the complex relationship between personal decisions and wider societal variables, this inclusive perspective aims to advance the understanding of the interplay of variables that occur in the management of diet-related diseases.

The integration of IT and healthcare within an RHMS not only underscores a seamless fusion of technological innovation with medical expertise but also serves as a manifestation of the collaborative synergy among these traditionally distinct domains. This unified approach is designed to empower both patients and physicians, fostering a shared platform in cutting-edge technology and medical expertise converge, as presented in Figure 1. This promises a paradigm shift towards more comprehensive and patient-centric healthcare

solutions, whereby patients benefit from personalized monitoring, timely recommendations, and online consultations, while physicians gain valuable insights and tools for more informed decision making.

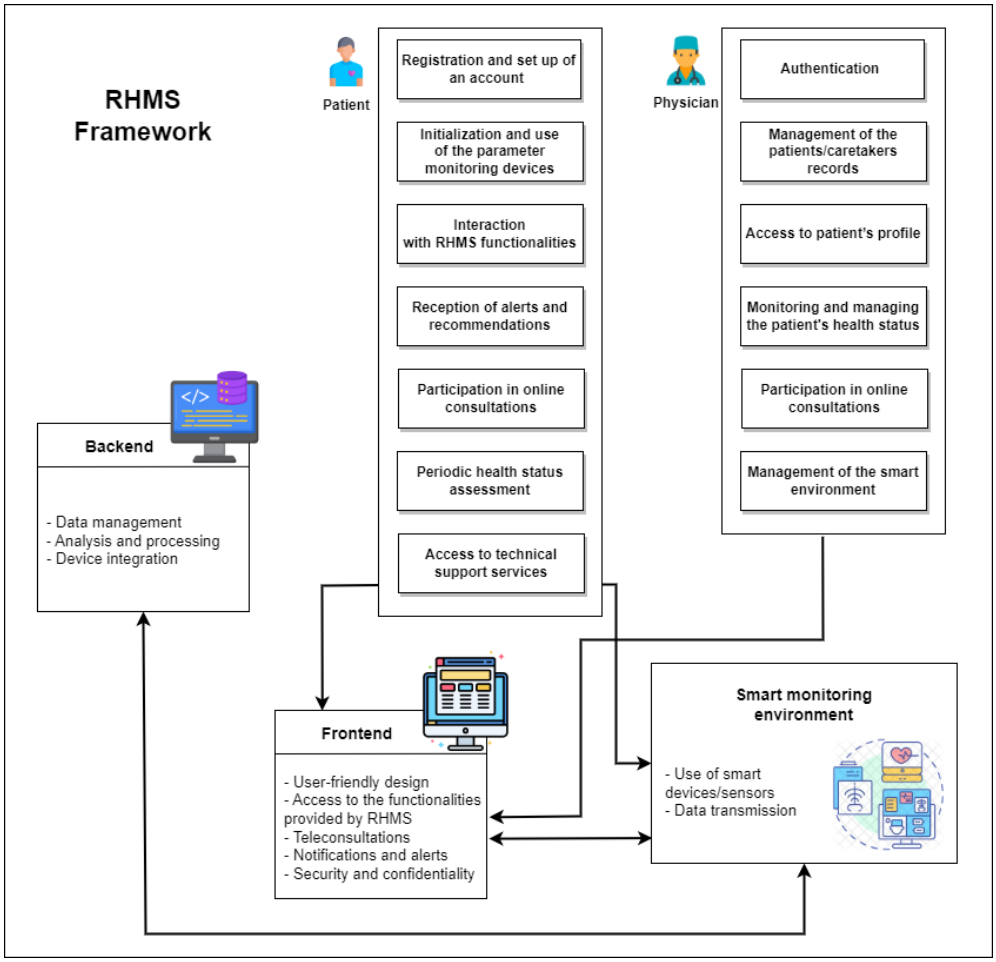

Figure 1. Schematic overview of RHMS and their provided comprehensive monitoring and disease management capabilities.

The *Smart Monitoring Environment* is the core technical infrastructure utilising an array of smart devices and sensors for the continuous monitoring of medical and environmental parameters. Data generated from these devices are efficiently transmitted to the digital health system, ensuring real-time data flow and analysis.

Patient engagement within the RHMS is initiated through the technical processes of personalized account registration and the seamless initialisation of parameter monitoring devices. These devices, often equipped with IoT capabilities, enable bidirectional data exchange, facilitating patient interactions with the system. The system employs algorithms for the generation of alerts and recommendations, fostering patient engagement in online consultations. The periodic analysis of reports involves data analytics algorithms, guiding adaptive behaviour or treatment changes. The system architecture incorporates robust technical support services, addressing potential system-related issues promptly.

For *physicians*, technical authentication and access mechanisms secure entry into the dedicated platform. Patient and caretaker records are meticulously managed within the system, utilising healthcare information systems. Access to patient profiles involves interoperability with patient profile records, allowing for comprehensive analysis of medical histories. The provision of personalized recommendations is facilitated through data analysis algorithms, guiding the adjustment of treatment plans. Technical support includes continuous interaction for progress monitoring, participation in online consultations, and

the generation of detailed technical reports and analyses. Configuration and customisation of smart environments for specific patients involve technical parameters and settings tailored to individual healthcare needs.

In the *backend*, technical prowess is showcased in the development of a robust system for storing and managing medical data. Security technologies, including encryption and access control mechanisms, ensure data security, confidentiality, accuracy, and integrity. Data analysis and processing involve the application of machine learning and artificial intelligence algorithms for interpreting collected data. Efficient processing is achieved through optimized databases and cloud computing infrastructure.

The *frontend* emphasizes technical considerations, such as user-friendly design principles, ensuring accessibility and ease of use for both patients and physicians. Security measures are implemented through encryption protocols, ensuring the protection of personal data. Technical options for controlling information privacy are integrated, involving granular access controls and consent management. The notification and alert system is technically configured for efficient and rapid communication between users and the system. Access to functionalities involves secure application programming interfaces (APIs) for health status monitoring, updating medical history, and supporting personalized medical decision making. Teleconsultations are enabled through the technical development of a secure communication platform, incorporating real-time interaction functionalities through video conferencing and secure messaging.

The rationales for considering integrated monitoring for diet-related disease management as a novel evaluation method *are presented as follows*:

- *Dynamic integration of multifaceted data streams*: Integrated monitoring is a new evaluation technique that stands out because it dynamically integrates several data streams that are specifically designed for the complexities of managing diseases connected to diet. This is in perfect harmony with the fundamentals of connected care, which emphasize the importance of constant real-time data flow from several sources [82]. In contrast to traditional methods, which concentrate only on certain metrics, including dietary intake, integrated monitoring extends its reach to include socioeconomic, environmental, and psychological data. This all-encompassing approach is designed to provide an in-depth understanding of the interactions among different aspects, making it especially appropriate for handling the complex relationships involved in treating diet-related diseases within an integrated care framework;
- *Next-generation precision obtained through smart technologies*: The innovative categorisation of integrated monitoring is emphasized by its dedication to accuracy, particularly with regard to the complexities of managing diseases connected to diets. Aligned with the concepts of connected care, integrated monitoring goes beyond conventional approaches by using advanced sensors, smart algorithms, and machine learning techniques [83];
- *Adaptive framework implies real-time responsiveness*: Integrated monitoring reflects the responsiveness demonstrated by connected care models through the development of an adaptable framework specifically designed for the real-time treatment of diet-related disorders. This approach enables continual assessment and change depending on new dietary patterns [84] as opposed to the static treatment programs used in traditional methods. Within the larger framework of connected care, integrated monitoring's real-time responsiveness guarantees that interventions match patients' changing dietary requests. This tailored and dynamic approach is essential for managing diet-related diseases effectively;
- *Synergistic interdisciplinary collaboration*: Its focus on integrated interdisciplinary collaboration aimed towards effective diet-related disease management, similar to the collaborative features of connected care, emphasizes the classification of integrated monitoring as a novel evaluation method. Integrated monitoring smoothly encompasses information from nutritionists, healthcare professionals, psychologists, and technology specialists [85,86] in contrast to traditional methods that are limited to

professional boundaries. This collaborative method guarantees a precision that is holistic and acknowledges the complex interactions of several factors. It is specially designed for the sensitive treatment of disorders related to nutrition within the context of digital health and the larger framework of connected care;

- *Integrated insights for comprehensive decision making*: The distinctive classification of integrated monitoring is strengthened by the integrated insights it offers, which facilitate complete decision making for the management of diet-related diseases. When combined with advanced analytics, a compilation of data streams provides healthcare professionals with an in-depth overview of their patients' health [87,88]. This broad knowledge enables well-informed decision making, allowing for customized procedures that take into account psychological, environmental, and socioeconomic issues in addition to nutritional considerations. This thorough approach promotes integrated monitoring as a novel method that surpasses conventional assessments, offering a complex and integrated outlook essential for efficient and individualized diet-related disease management.

2.2. Tailored Patient-Centric RHMS—RO-SmartAgeing System, NeuroPredict Platform, and HepatoConect System

The traditional generic approach has become inadequate in the context of diet-related disease management because it does not address intrinsic complexity and individual differences that are common in patients' health evolutions. Tailoring an RHMS ensures that patients receive personalized health insights that resonate with their unique health profiles.

The failure of an all-encompassing approach becomes clear in the dynamic field of RHMS. Three RHMS—RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system—adopt a patient-centric approach that recognizes the complexities of health pathways. These solutions prioritize individualized experiences for patients, including insights, customized monitoring, real-time feedback, and easy integration into daily life. Tailored RHMS provide accuracy for health professionals through focused interventions, supported individualized diagnoses, simplified communication, effective resource allocation, and data-driven decision making.

2.2.1. RO-SmartAgeing System

The RO-SmartAgeing system was developed within a research project titled "Non-Invasive Monitoring System and Health Assessment of the Elderly in a Smart Environment", completed at the end of 2022. The RO-SmartAgeing system represents an innovative and comprehensive approach to the remote health monitoring of elderly individuals, integrating various technologies to create a personalized and efficient healthcare solution. This system is designed to monitor and assess the health status of elderly individuals, promoting independence, preventing potential health issues, and enhancing overall well-being.

At its core, the RO-SmartAgeing system incorporates wearable noninvasive motion and physiological sensors, enabling the collection of essential medical parameters. These wearables provide continuous monitoring, offering insights into the individual's health and facilitating early intervention when necessary. Additionally, discreet ambient and medical sensors are strategically placed to monitor daily activities and lifestyle, capturing data that contribute to a holistic understanding of the individual's well-being.

The smart monitoring environment created by the RO-SmartAgeing system is tailored to each elderly patient, adapting to their specific medical needs and evolving over time. The cloud platform serves as a central hub for data storage and aggregation, facilitating advanced data analysis. This analysis yields personalized insights into a patient's health status, contributing to a proactive and individualized approach to healthcare. The creation of a smart monitoring environment for each patient involves a meticulous process. Each patient is enrolled in the database, and every device is assigned a unique identifier associated with the patient. Discrete devices like Withings ensure secure and automated updates.

The tailored smart environment adapts to the patient's medical specifications and evolves through cloud-based configuration.

The main services provided by the RO-SmartAgeing system include personalized biomedical, environmental, and movement parameter monitoring. This encompasses continuous assessment and diagnosis support, fall prevention, assistance for home autonomy, and alert services in case of physical accidents or environmental malfunctions. Furthermore, the system focuses on enhancing social relationships, providing support for caregivers, and facilitating online communication to improve caregiving knowledge.

The support services component of the system plays a pivotal role by offering information and recommendations tailored to the daily life needs of older individuals and their caregivers. This component is instrumental in ensuring that the system not only monitors health parameters but also addresses the broader spectrum of requirements associated with ageing individuals, promoting a holistic approach to healthcare.

The medical component of the system plays a crucial role in centralising and managing information associated with monitored individuals. It supports the personalized configuration of the smart environment based on the patient's medical specifics and lifestyle. Authentication mechanisms ensure controlled access for multiple user roles, including doctors, caregivers, specialists, and patients. This part of the RO-SmartAgeing system is characterized by its ability to centralize and manage information related to monitored individuals. It serves as a unified point of access with controlled entry for various user roles, including doctors, caregivers, specialists, and patients. This centralized approach facilitates a seamless flow of information and ensures that each user receives data relevant to their role and responsibilities. Within the medical component, several modules contribute to the effective functioning of the system. The management modules for patients, caregivers, and specialists enable organized oversight of individuals under care. Additionally, modules for personalized smart environment configuration, alert management, monitoring plans, and treatment plans enhance the system's capability to provide individualized and proactive healthcare.

RO-SmartAgeing system—a smart solution for diet-related disease management

Beyond its primary focus on remote health monitoring for the elderly, the system's comprehensive approach and personalized features make it a promising platform for addressing the intricate challenges associated with diet-related diseases. The main capabilities that are associated with diet-related disease management are presented as follows:

- *Precision monitoring of biomedical parameters*: One of the key strengths of the RO-SmartAgeing system lies in its ability to offer precision monitoring of biomedical parameters. Wearable noninvasive sensors embedded in the system continuously track vital health indicators related to diet, such as heart rate, physical activity, and sleep patterns. This real-time data provide a detailed picture of an individual's health, allowing for early detection of anomalies or deviations that may be indicative of diet-related issues;
- *Dietary adherence tracking*: Effective management of diet-related diseases often hinges on strict adherence to dietary guidelines. The RO-SmartAgeing system can play a pivotal role in supporting individuals with diet-related conditions by incorporating features that track dietary habits. Integration with smart devices and applications allows users to log their dietary intake, enabling healthcare professionals to assess adherence to prescribed diets and make timely interventions or adjustments;
- *Holistic lifestyle monitoring*: Diet-related diseases are often intertwined with lifestyle factors. The RO-SmartAgeing system's ambient sensors capture data related to daily activities and living conditions, providing a holistic understanding of an individual's lifestyle. This comprehensive insight goes beyond conventional dietary metrics, encompassing environmental factors that may impact dietary choices and overall health;
- *Personalized health insights*: The cloud-based analytics of the RO-SmartAgeing system contribute to the generation of personalized health insights. Advanced data analysis, informed by a wealth of collected information, allows for the identification of

patterns and correlations specific to an individual's health profile. This includes understanding how dietary choices influence various health parameters, offering tailored recommendations for optimal diet-related disease;

- *Connected care and collaborative approach*: The RO-SmartAgeing system promotes connected care by fostering communication and collaboration among healthcare providers, patients, and caregivers. In the context of diet-related disease management, this interconnectedness becomes crucial. Healthcare professionals can remotely assess dietary data, provide timely feedback, and engage in a collaborative approach to tailor interventions based on real-time health information;
- *Empowering patients for self-management*: Beyond its utility for healthcare professionals, the RO-SmartAgeing system empowers individuals to actively participate in the management of their diet-related conditions. Access to personalized health data, dietary insights, and real-time feedback encourages users to make informed choices, fostering a sense of autonomy and self-efficacy in managing their dietary health;
- *Prevention and early intervention*: The proactive nature of the RO-SmartAgeing system positions it as a powerful tool for preventing and intervening in diet-related health issues. By continuously monitoring relevant parameters, the system can identify trends that may precede adverse health events. This early detection enables timely interventions, potentially preventing the escalation of diet-related conditions and associated complications.

2.2.2. NeuroPredict Platform

The "Advanced Artificial Intelligence Techniques in Science and Applications" is a research project started recently, in 2023. One of its objectives is to evolve the NeuroPredict Platform as a key biomedical component.

The primary objective of the NeuroPredict Platform is to develop predictive models geared towards the prevention, early detection, and long-term monitoring of individuals with neurodegenerative conditions. These models are intricately linked to a diverse array of medical data and information obtained through nonintrusive intelligent monitoring, alongside clinical data sourced from patients, inclusive of open data repositories. The inception of the NeuroPredict Platform stems from the groundwork laid by the smart remote monitoring environment for the elderly, the RO-SmartAgeing system, which was developed within the overarching project. This environment is meticulously crafted to align with the unique features of neurodegenerative diseases and is supplemented with smart devices tailored to these specific health challenges.

The NeuroPredict Platform is underpinned by three key pillars:

- Comprehensive monitoring of health parameters, ongoing activities, behaviour, and lifestyle through meticulous data collection within a personalized intelligent environment. This encompasses the integration of IoMT devices designed for monitoring health parameters, such as heart rate, electrocardiogram (ECG), blood pressure, pulse, sleep-related metrics, body positioning, bioelectrical impedance analysis, body fat, muscle mass, bone mass, and more. It also encompasses ambient parameters and sensors for motion and physical activity;
- Leveraging of open data sources specifically for neurodegenerative conditions;
- Integration of data and insights derived from established cognitive tests (e.g., Mini-Mental Test Examination (MMSE) and Alzheimer's Disease Assessment Scale-Cognitive (ADAS-Cog)) to formulate predictive models catering to the prevention, early detection, and ongoing monitoring of individuals with neurodegenerative conditions. All amassed data are meticulously stored in a database and subjected to cloud-based AI analyses to pinpoint patterns associated with cognitive status.

Data correlated with patients' medical histories and real-time inputs from various IoMT devices will find a repository in the ICIPRO cloud. These data are subsequently transmitted to the specialized AI-driven predictive monitoring platform tailored for patients

dealing with neurodegenerative conditions, facilitating AI algorithms in prognosticating the longitudinal progression of their health.

The overarching research endeavours are focused on the establishment of multivariate AI-driven predictive models for neurodegenerative diseases. These models will seamlessly integrate the high-dimensional data aforementioned to adeptly identify, assess, and monitor patients grappling with these conditions. Additionally, the intention is to assimilate select vital parameters measured through (bio)markers identified as particularly predictive for certain neurodegenerative conditions. The data analytics will adopt a longitudinal approach.

The NeuroPredict Platform champions a proactive and preventive management approach to neurodegenerative diseases. Drawing from available public information, current estimations posit that Romania lacks a comparably intricate computer system akin to the NeuroPredict Platform. The platform is conceived as a patient-centric, accessible, and minimally invasive tool with the flexibility for customisation based on medical intricacies. Its envisioned deployment spans both patient homes and medical care units. The complexity of the platform manifests through a diverse range of functionalities encompassing health status monitoring, ongoing activity tracking, activity detection, alert mechanisms for unforeseen events or aberrant values, and support mechanisms for monitored patients and healthcare providers, all augmented by a predictive dimension specifically tailored for neurodegenerative conditions.

The specific aspects of the NeuroPredict Platform lie in the following:

- The formulation of a novel model for personalized, proactive, and predictive care anchored in datasets sourced from medical contexts and shaped within a responsive intelligent environment. It dynamically reacts to the evolving health status of the patient, instantaneously identifies health concerns, issues timely alerts, supports patients in managing their health, and provides enduring support to medical professionals in crafting decisions, including those spanning the long term;
- The compilation of an extensive array of medical, lifestyle, and behavioural parameters culminating in the creation of a tangible dataset. Coupled with specialized AI processing methodologies, this dataset is pivotal in crafting and validating personalized predictive models through longitudinal analyses;
- The scalable architecture of the platform and the smart monitoring environment, foster the seamless integration of emerging smart devices designed for measuring additional medical and behavioural parameters. This scalability augments the spectrum of functionalities and enhances alignment with the dynamic landscape driven by the convergence of the IoMT, AI, and intelligent health monitoring.

NeuroPredict Platform—A smart solution for diet-related disease management

As it was developed on the grounds of the RO-SmartAgeing smart monitoring environment, in addition to the capabilities presented in Section 2.1 for the RO-SmartAgeing system, presented here are some others for diet-related disease management addressing a patient with a neurodegenerative disorder:

- *Predictive modelling*: The platform generates prediction models based on a mix of health, lifestyle, and dietary information using powerful AI. These models can predict how dietary changes may affect health outcomes over time. This proactive, predictive capability enables patients and healthcare professionals to make knowledgeable choices on disease prevention and treatment dietary strategies;
- *Cognitive health integration*: The NeuroPredict Platform integrates cognitive health data as essential components, going beyond typical health monitoring. The platform provides insights into how dietary habits impact cognitive well-being by taking in data from cognitive tests such as the MMSE and ADAS-Cog. This integration is especially useful in the context of diet-related disorders with neurological consequences, since it provides a comprehensive view of the association between nutrition and cognitive health;

- *Personalized nutritional guidance*: The platform's AI capabilities extend to individualized dietary guidance. It personalizes recommendations based on a patient's distinct health profile, habits, and cognitive status. This tailored approach is critical in avoiding the generic limitations of traditional nutritional management, ensuring that options are properly customized for the particular requirements of each patient;
- *Adaptive cognitive support*: The platform identifies the cognitive aspect of diet-related disorders and delivers adaptive cognitive assistance. This entails customized procedures targeted at protecting cognitive function via dietary actions. The platform takes an active role in the cognitive well-being of individuals managing diet-related diseases, whether by recommending brain-boosting nutrients or adapting dietary plans for preventing cognitive decline;
- *Use of open data sources*: The NeuroPredict Platform distinguishes itself by making use of open data sources associated with neurodegenerative disorders. The platform expands its repository of information through the integration of a wide range of external data, such as findings from research and clinical insights. This integration improves the platform's ability to provide trained guidance and keep up with the most recent discoveries in the field of diet-related disorders;
- *Improved caregiver assistance*: Recognising the importance of caregivers in the management of diet-related disorders, the NeuroPredict Platform encompasses features that offer assistance and guidance to those helping patients. This broad approach transcends the individual patient, taking into account the whole system involved in dietary control, promoting holistic support;
- *Longitudinal analysis*: Understanding the long-term impacts of dietary strategies calls for the platform's capacity to store and analyse data longitudinally. It allows for the detection of trends, patterns, and correlations across time, resulting in a more in-depth understanding of the multifaceted relationship between diet and wellness in the setting of chronic disorders.

2.2.3. HepatoConect System

The HepatoConect system is a currently under-development solution tailored for patients with LC. It is designed to enable home monitoring allowing patients to be under the expert guidance of gastroenterologists. Acknowledging the distinctive challenges linked to LC management, the HepatoConect system utilizes smart technologies for delivering personalized health insights and continuous real-time monitoring.

The key features of the HepatoConect system are as follows:

- *Customized assistance for gastroenterologists*: The HepatoConect system is made with careful consideration to meet the specific requirements of gastroenterologists who are involved in the complex management of LC. Through the smooth integration of telemedicine and health informatics, the HepatoConect system provides gastroenterologists with remote monitoring of their patients;
- *Ensuring efficient management of liver cirrhosis*: Adaptive approaches to the management of the disease are integrated into HepatoConect because it acknowledges the dynamic nature of LC. Because the system responds in real-time to data, gastroenterologists may make informed choices on protocols for treatment, dietary changes, and lifestyle adjustments. This flexible approach improves the accuracy and efficiency of managing LC;
- *Advanced technologies for at-home monitoring*: The HepatoConect system uses IoMT devices to gather a variety of health parameters. It integrates technologies specifically designed for an at-home smart monitoring environment. Cloud-based technologies enable gastroenterologists to securely access real-time data on vital signs, liver function tests, and other relevant health parameters. With alerts triggered for any discrepancies from reference parameters, this allows for continuous monitoring. Gastroenterologists have access to an exhaustive overview of their patients' health status due to wearable devices, which guarantee an uninterrupted data flow;

- *Personalized health insights driving decision making*: One of the main features of the HepatoConect system is its capacity to provide tailored health insights based on information and data that are monitored. By examining patient-specific patterns, gastroenterologists can find links between behaviours and the course of illness. Because of the scalable feature of the system, alerts and recommendations may be made according based on the distinctive profiles of specific patients, ensuring relevant information in line with precise disease management methods;
- *Empowering both patients and gastroenterologists*: By smoothly integrating patient precise health data into healthcare management, the HepatoConect system acts as an empowering tool for both patients and gastroenterologists. Patients may provide access to personal health data, which include dietary habits, medication adherence, and symptoms, by using safe data transmission methods. A thorough patient profile that is enhanced with real-time data is made available to gastroenterologists, facilitating informed and participatory decision making. This combined involvement improves patient outcomes and enables gastroenterologists a comprehensive picture of their patients' health trends;
- *Integrated lifestyle support*: The HepatoConect system goes beyond medical recommendations by providing lifestyle assistance specifically designed to meet the requirements of individuals with LC. The system enhances overall well-being by encouraging compliance to recommended changes in lifestyle and offering actionable insights that integrate with everyday routines;
- *Symptom tracking*: The implementation of a capability that tracks symptoms, such as ascites, jaundice, and fatigue, to enable patients to report and keep track of symptoms related to LC. This information assists in evaluating the impact of the disorder on the patient's everyday life;
- *Dietary recording and analysis*: Integration of a dietary tracking capability that allows patients to record their daily food consumption. By analysing dietary data, the system can offer tailored nutritional recommendations to support liver health, as well as insights into dietary patterns;
- *Resources for psychological support*: Information and resources about mental health, coping mechanisms, and psychosocial support are provided. Educational resources and materials about liver health, managing LC, and changing one's lifestyle are also provided. The information contained herein may be updated regularly and customized to the patient's particular situation, promoting lifelong learning and empowerment. Taking care of patients' mental health might be essential to managing long-term diseases like LC.

HepatoConect System—A smart solution for diet-related disease management

Uniquely tailored to address the distinctive challenges associated with liver health, the HepatoConect system provides solid capabilities for diet-related disease management, as follows:

- *Personalized dietary guidance*: HepatoConect system excels in crafting personalized dietary plans that are carefully chosen for patients suffering from LC, based on the patient's specific liver health, dietary restrictions, and nutritional requirements. This aspect guarantees that nutritional therapies are tailored to the specific requirements of every patient, promoting liver function at its best;
- *Symptom monitoring and reporting*: The HepatoConect system goes further than conventional tracking by providing patients with an online tool to continuously monitor and report symptoms related to LC. Patients may report their symptoms easily due to an intuitive interface, which allows them to provide important information to assist with more precise evaluations within the management of the patient;
- *Educational resources*: With evidence that is updated frequently and customized to each patient's particular situation, the system is a valuable source of health and wellness knowledge. Patients can make informed choices using educational resources on liver health, dietary recommendations, and lifestyle changes;

- *Continuous physiological monitoring*: By leveraging wearable technology to provide continuous physiological monitoring, the HepatoConect system expands its monitoring capabilities. This guarantees the real-time monitoring of vital health data, including heart rate, activity level, and sleep patterns, providing patients and healthcare professionals with a thorough picture;
- *Remote gastroenterologist interaction and teleconsultation*: The HepatoConect system enables patients to interact with gastroenterologists virtually through teleconsultations. By guaranteeing ongoing interactions between patients and healthcare professionals, this capability enables fast updates to treatment plans and procedures in response to the patient's changing health status;
- *Automated alerts for significant medical conditions*: The HepatoConect system includes an automated alert capability that automatically sends out warnings for important medical conditions to improve care for patients. Whether identifying unexpected shifts in vital signs or indicating possible drug interactions, these notifications allow healthcare professionals to respond and act promptly.

2.3. Methods for the Development of the Tailored RHMS

The shared methods employed in crafting our three tailored RHMS (the RO-SmartAgeing System, NeuroPredict Platform, and HepatoConect System) are presented as follows:

- *Research-driven development*: the inception of our RHMS involves building upon a strong scientific foundation, aligning closely with research findings to create solutions grounded in evidence and innovation.
- *Common framework and elements*: RHMS development initiates by establishing an integrated insights framework, ensuring coherence and seamless integration of medical and technological insights throughout the design and development stages.
- *Multidisciplinary collaboration*: In the early stages, a collaborative effort brings together healthcare and IT experts, including the authors of this paper. This collaborative approach lays the groundwork for integrating medical insights with technological innovation.
- *Data-driven architecture*: Throughout development, a unified method employs cloud platforms for data storage and aggregation. This architecture guarantees scalability, flexibility, and secure access, maintaining consistency across RHMS.
- *Smart monitoring environment*: Emphasising the design process, we prioritize creating a smart monitoring environment tailored to individual patients and disease management. This comprehensive approach integrates wearables, ambient sensors, and cloud-based platforms for health monitoring.
- *Wearable technology integration*: implementation includes seamlessly integrating wearable noninvasive sensors for personalized and adaptive monitoring tailored to individual health needs.
- *AI and predictive modelling*: we incorporate advanced AI techniques for predictive modelling, ensuring a proactive and personalized healthcare approach across diverse health conditions.
- *Data analysis, storage, and security*: Real-time analysis and processing of collected data are implemented. Cloud-based storage acts as a central repository for organized and accessible health data, supporting advanced analytics for personalized insights, with robust security measures ensuring confidentiality, security, and integrity.
- *Ensuring remote healthcare access*: this involves facilitating efficient remote healthcare access and empowering healthcare professionals to monitor and engage with patients, especially in managing chronic conditions.
- *User interface design*: During development and implementation, a unified approach prioritizes an intuitive and accessible user interface. This ensures ease of use for patients, caregivers, and healthcare professionals, enhancing the overall user experience.

In the context of our paper, the smart monitoring environment and data accuracy and evaluation are highlighted and presented considering the development of capabilities of the three tailored RHMS to be a novel evaluation method for diet-related disease management.

2.3.1. Smart Monitoring Environment

Smart monitoring environments, which logically integrate a wide range of smart devices, are essential to the shift in diet-related disease management. For instance, bioelectrical impedance analysis (BIA) is being used in smart scales and other devices to provide healthcare professionals more advanced knowledge of body composition, including fat, muscle mass, and hydration levels [89]. This level of detail is essential for customising dietary guidance and enabling targeted actions that focus on certain health issues for patients. The integration of contactless thermometers has a significant influence on illnesses linked to nutrition. These devices make it easier to take an accurate temperature without coming into touch with the patient, which is essential for tracking fever, a major sign of many diet-related disorders. Healthcare professionals acquire a useful tool for the early identification and timely management of any issues by incorporating such devices. Fitness trackers and other wearable technology greatly enhance remote monitoring and customized treatment [90]. Healthcare professionals can use real-time data from the continuous monitoring of vital signs, such as blood oxygen saturation and heart rate, to identify patterns and detect deviations from the normal range. This degree of understanding is essential for customising dietary and other interventions so that they reflect the patient's changing health condition.

These gained insights render them even more useful by facilitating reliable data transmission for remote monitoring. This is especially helpful for managing diseases linked to dietary habits when following meal planning and making lifestyle changes are essential. Healthcare professionals may monitor patients remotely, act quickly to address deviations, and deliver timely care by using integrated monitoring settings.

The RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system are based on tailored smart monitoring environments; each of them can also be personalized according to the long-term particularities of every monitored patient. The main smart devices that are suitable for these smart environments are presented as follows:

1. ***Withings BPM Core*** [91]:
    - *Functionality*: offers advanced cardiovascular monitoring with ECG, blood pressure, and pulse measurements;
    - *Healthcare application*: Vital for patients with cardiovascular conditions, providing healthcare professionals with real-time, clinical-grade data. Enables remote monitoring of cardiac health, allowing for timely intervention and reducing hospital visits.
2. ***Withings Move ECG*** [92]:
    - Functionality: combines ECG measurements, continuous heart rate tracking, and activity monitoring;
    - Key features:
    - Heart rate sensor: provides continuous heart rate monitoring, essential for assessing cardiovascular health;
    - Three-axis accelerometer: tracks movement patterns, offering insights into daily activities and exercise routines;
    - Built-in GPS: delivers precise location tracking, particularly valuable for outdoor workouts and activities;
    - Activity tracking: monitors various metrics, including activity duration, step count, and calories burned during physical activities.
    - Healthcare application: Useful for patients with heart conditions. Facilitates long-term heart health tracking, aiding in the assessment of treatment efficacy and lifestyle impact.

3. ***Withings Body+*** [93]:
    - Functionality: utilizes BIA for comprehensive body composition analysis, including weight, body fat, muscle mass, water content, and bone mass;
    - Healthcare application: Essential for weight management and chronic disease care. Enables remote monitoring of patients' nutritional status and overall health, contributing to personalized care plans.
4. ***Withings Sleep Analyzer*** [94]:
    - Functionality: monitors various sleep parameters, including respiratory rate, heart rate, body movements, snoring, and interruptions;
    - Healthcare application: Useful for addressing sleep disorders. Enables remote monitoring of patients' sleep patterns, facilitating accurate diagnoses and treatment adjustments.
5. ***Withings Thermo*** [95]:
    - Functionality: infrared temporal thermometer for contactless temperature measurement;
    - Healthcare application: Ideal for remote patient monitoring. Allows for remotely tracking patients' temperature trends, aiding in the early detection of infections and optimising telehealth consultations.
6. ***Withings BodyScan*** [96]:
    - Functionality: provides detailed weight measurements, segmental body composition analysis, and ECG with six derivations;
    - Healthcare application: Integral for preventive care. Enables remote patient monitoring with detailed health assessments, fostering proactive interventions and personalized healthcare strategies.
7. ***Fitbit Charge 5*** [97]:
    - Functionality: versatile wearable device equipped with sensors designed for comprehensive health and activity monitoring;
    - Key features:
    - Heart rate sensor, three-axis accelerometer, built-in GPS, and activity tracking;
    - Oxygen saturation (SpO2) sensor: measures blood oxygen levels, contributing to respiratory health assessment.
    - Healthcare application: The continuous heart rate monitoring and SpO2 measurements provide valuable data for assessing and tracking cardiovascular health. Healthcare professionals can leverage this data for early anomaly detection and personalized patient care.
8. ***Glucometer CareSens*** [98]:
    - Functionality: a portable device designed for the rapid and precise measurement of blood glucose levels, crucial for effective diabetes management;
    - Key features:
    - Rapid and precise measurements: offers quick and accurate blood glucose readings, facilitating efficient diabetes monitoring;
    - Data storage: capable of storing historical data, enabling long-term tracking and trend analysis for healthcare professionals.
    - Healthcare application: Enables the crucial role in monitoring and managing blood glucose levels for individuals with diabetes. Healthcare professionals can remotely access and analyse stored data, allowing for personalized treatment plans and timely interventions.
9. ***MySignals EMG*** [99]:
    - Functionality: This is a comprehensive biometric monitoring device specifically designed for capturing electromyography (EMG) signals. It captures and

records electrical signals from muscles, offering insights into muscle activity and performance;
- Healthcare application: Assesses muscle function, detecting abnormalities, and monitoring rehabilitation progress. These data can be used for personalized treatment planning and rehabilitation strategies;

10. ***Moodmetric Smart Ring*** [100]:
    - Functionality: uses electrodermal activity (EDA) measurements to monitor stress levels and emotional well-being;
    - Healthcare application: Enables assessing and managing stress-related conditions. The continuous stress data can aid in tailoring stress-reduction interventions and monitoring the effectiveness of stress management strategies.
11. ***Sensoria Smart Socks*** [101]:
    - Functionality: equipped with sensors to monitor various parameters related to gait and foot dynamics;
    - Key features:
    - Gait analysis: captures data on cadence, foot landing, and impact forces during walking or running;
    - Pressure distribution: measures how weight is distributed on the feet, offering insights into gait abnormalities.
    - Healthcare application: Enables assessing gait abnormalities in patients with neurological or musculoskeletal conditions. These data aid in designing targeted interventions, monitoring rehabilitation progress, and preventing complications related to gait disorders.
12. ***Medical Blackbox*** (designed and developed as part of the RO-SmartAgeing project) [102]:
    - Functionality: integrates diverse sensors into an Arduino-Mega-based platform for comprehensive health monitoring;
    - Key sensors:
    - SpO2 sensor: measures pulse rate and oxygen saturation, vital for respiratory health monitoring;
    - Alcohol detection sensor: high sensitivity to alcohol vapours, relevant for addiction rehabilitation and monitoring;
    - ECG sensor: facilitates clinical-grade electrocardiogram measurements for cardiovascular health assessment;
    - Color sensor: detects colour variations in urine strips, aiding in kidney function assessment;
    - Temperature Sensor: enables accurate and remote temperature monitoring.
    - Healthcare application: Essential for patients with chronic respiratory, cardiac, or renal conditions, allowing healthcare professionals to remotely assess vital parameters. Enables timely intervention and reduces the need for frequent clinic visits.
13. ***Ambiental Blackbox*** (designed and developed as part of the RO-SmartAgeing project) [103]:
    - Functionality: integrates various sensors into an Arduino-Uno-based platform for environmental monitoring;
    - Key sensors:
    - Motion sensor: detects movement changes, valuable for patient activity monitoring and fall detection;
    - Gas sensor: identifies combustible gases, smoke, and volatile organic compounds, crucial for indoor air quality assessment;
    - Temperature and humidity sensor: monitors environmental conditions, aiding in patient comfort and health;
    - Light sensor: measures ambient light levels, supporting circadian rhythm assessment;
    - Air quality sensor: detects CO_2 levels, providing insights into indoor air quality.

- Healthcare application: Ensures optimal conditions for patients. Monitors changes in patient activity and environmental parameters, contributing to enhanced patient well-being.

14. ***Gaitband*** (designed and developed as part of the RO-SmartAgeing project) [104]:
    - Functionality: integrates an accelerometer, gyroscope, and Wi-Fi module for real-time posture and gait analysis; it captures movement data, enabling precise gait analysis;
    - Healthcare application: Enables continuous monitoring of posture and gait, providing valuable insights for treatment adjustments and personalized care plans. Remote accessibility optimizes patient care, especially in telehealth scenarios.

Currently, the Withings BPM Core, Withings Move ECG, Withings Body+, and Withings Sleep Analyzer are integrated into the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system; Withings Thermo, Fitbit Charge 5, Glucometer CareSens, Medical Blackbox, Ambiental Blackbox, and Gaitband are integrated into the RO-SmartAgeing system and NeuroPredict Platform; Withings Body Scan, MySignals EMG, Moodmetric Smart Ring, and Sensoria Smart Socks are integrated into NeuroPredict Platform.

2.3.2. Data Accuracy and Evaluation

In the context of mitigating diet-related disorders, ensuring data quality and putting in place efficient evaluation processes are critical components of RHMS and smart monitoring environments. The accuracy and consistency of the data that these systems gather are essential to their efficacy [105], since healthcare professionals use these data to customize therapies and make well-informed judgments.

The integration of various sensors and devices adds to a comprehensive dataset in diet-related disease management. Precise measurements are necessary to evaluate how dietary modifications affect general health.

Wearable fitness trackers and other continuous monitoring devices offer real-time data on vital indicators including blood oxygen saturation and heart rate. These measures must be accurate, since inconsistencies might indicate dietary-related health issues for the patient. Reliable assessment methods, such as calibration processes, are required to provide trustworthy continuous monitoring.

The evaluation of data is aided by the integration of AI and machine learning algorithms in RHMS. These algorithms provide insights, find patterns in large datasets, and analyse them [106]. However, the calibre of training data and continuous validation procedures determine how accurate are AI-driven evaluations. Inaccurate or a lack of initial data may result in inaccurate conclusions and hinder the ability of these technologies to improve the management of diet-related diseases.

From a patient perspective, data accuracy is just as important. Patients depend on the data provided by smart devices to make educated decisions regarding their food habits and general health. Inaccurate information may cause people to compromise their confidence in this technology [107] and become less involved in their own healthcare.

Using a variety of key strategies and best practices is necessary to ensure data accuracy in the context of smart monitoring environments in the management of diet-related diseases:

- *Calibration and regular maintenance*: To ensure accuracy, monitoring devices like glucose meters and smart scales must be calibrated regularly [108]. To guarantee that the devices continue to deliver accurate measurements over time, users and healthcare providers should perform routine maintenance checks and upgrades;
- *Integration of multiple data sources*: Accuracy may be improved by integrating data from several sources [105]. Using data from many devices to cross-reference and correlate provides a more accurate and thorough overview of a patient's health status;
- *User education and training*: It is critical for educating users—including patients and healthcare providers—on how to properly use the devices from smart monitoring

environments [109]. Training curricula have to include proper placement, measuring techniques, and any particular needs for precise data collection. Users need to be conscious of issues like fasting times and where to place their wearables appropriately, which might affect measurements;

- *Regular software updates*: It is critical to maintain device software updates. Updates that improve the device's functionality and fix any accuracy-related problems are frequently provided by manufacturers. Frequent updates can increase the accuracy of data gathering and analysis [110];
- *Privacy and security measures*: Ensuring strong security and privacy measures is tangentially related to data accuracy. If users have trust in the confidentiality of their health data, they are more likely to provide correct information. Protocols for secure data transfer and storage add to the overall trustworthiness of the information gathered.

Ensuring the quality of health information is crucial, and this includes evaluating data accuracy in RHMS for diet-related illness management. Rigorous evaluation processes support users, researchers, and healthcare professionals to assess the accuracy and reliability of data generated by different monitoring equipment. Several *key considerations contribute to the evaluation of data accuracy* in this context, as follows:

- *Comparative analysis*: Comparative analyses are used to evaluate the accuracy of smart devices by comparing their measurements with those of clinical-grade equipment or established reference standards [111]. This assessment method highlights any inconsistencies that would need to be corrected and offers insights into the device's accuracy;
- *Accuracy across varied patients*: It is important to assess the data's accuracy across a range of demographic categories, taking into account variables including age, gender, ethnicity, and health status. Ensuring consistent performance of smart devices across different patient groups improves their portability and suitability for use in a variety of healthcare settings;
- *Longitudinal monitoring*: Monitoring longitudinally entails evaluating the data's accuracy over an extended time frame [112]. This method assists in finding any gradual deviations or deteriorations in device performance. A device's accuracy maintenance with extended use is an important consideration in determining how reliable it is for treating diet-related chronic diseases;
- *User feedback*: Feedback from users offers insightful information on the usefulness and accuracy of smart monitoring devices. Assessing user experiences and opinions facilitates the identification of possible problems, usability issues, and areas in need of development. Good user experiences are frequently correlated with the monitoring system's overall accuracy and efficacy;
- *Real-world use cases*: It is important to assess data accuracy in real-world situations, such as the everyday lives of patients and hospital environments [113]. Given the dynamic nature of managing diet-related diseases, knowing how effectively smart devices function in real-world settings guarantees their applicability and efficacy in a range of healthcare settings;
- *Validation by healthcare professionals*: It is essential that healthcare professionals participate in the evaluation process. Physicians can offer insightful information on the accuracy and clinical usefulness of smart monitoring data. Their confirmation provides a level of expert examination that strengthens trust in the accuracy of the data gathered;
- *Continuous improvement*: Mechanisms for continuous enhancement based on pursuing evaluations should be included in RHMS. Consistent software and algorithm changes, guided by assessment outcomes and feedback, help preserve and improve data accuracy over time;
- *Interoperability and integration*: It is critical to evaluate the degree to which smart devices interact and exchange data with the current healthcare infrastructure. By ensuring that precise data are readily integrated into more comprehensive healthcare

analytics, interoperability improves the general quality of patient care and illness management [114].

We present the conceptual framework (Figure 2) that outlines a comprehensive strategy for the three RHMS tailored for managing diet-related diseases. Fundamentally, the framework integrates a wide range of data sources, including patient history, medical and environmental devices, open data, and inputs from dietary questionnaires or teleconsultations. To ensure data integrity and usability, this heterogeneous data stream is carefully transmitted using technologies such as Wi-Fi, Bluetooth, or a global system for mobile communication (GSM), and subsequently administered through a series of preprocessing steps, such as filtering, clearing, and aggregation, with temporary storage locally. Considering the sensitive nature of health data, enhanced attention is given to data security throughout the process. Once preprocessed, these data are transmitted to the cloud processing modules, where they undergo further analysis. It is important to note that data are processed once in the cloud before being permanently stored and a suite of applications and analysis tools await, including alarms triggering, diagnostic support services, nutritional status evaluation, AI-predictive models, or wellness and activity tracking. The AI-based predictive models are trained and tested using the open data available and the specific data from the patients as well as their measured parameters. The models are based on ML algorithms that are specific to different types of data, such as support vector machine, decision tree, or random forest. The framework also underscores the importance of user interaction, fostering seamless communication and collaboration between patients and healthcare professionals. As data flows through the system, paramount considerations of data accuracy, quality, and security are maintained to ensure the reliability and effectiveness of the RHMS in diet-related disease management.

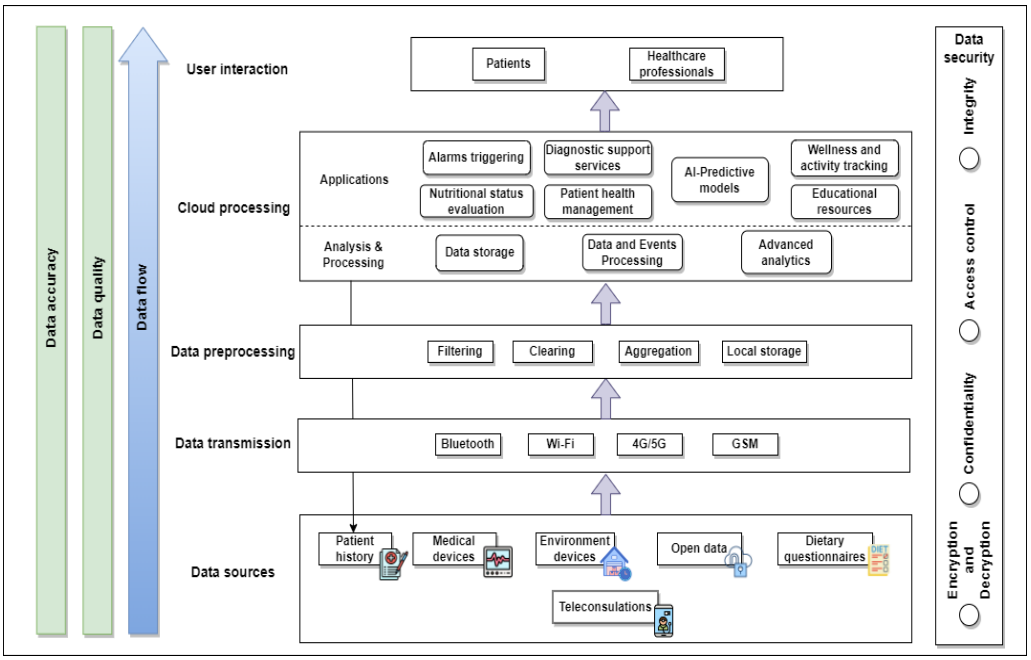

Figure 2. Conceptual framework of the three tailored RHMS.

The cornerstones of successful RHMS and smart monitoring environments, especially in the management of diet-related disorders, are upholding data accuracy and putting in place efficient update procedures. Reliable data provide the foundation for healthcare professionals' well-informed decision making, which results in patient treatments that are more efficient and customized. Ensuring the integrity of these systems requires regular validation, calibration, and compliance with best practices in data management.

2.4. Comprehensive Monitoring, Medical Integration

The usefulness of smart monitoring environments for diet-related disease management is greatly enhanced when they are combined with medical integration and comprehensive monitoring, especially when an RHMS is involved. The thorough comprehension of an individual's health condition is enhanced by the easy integration of diverse monitoring technologies that cover an extensive range of health variables.

The integration of the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system into comprehensive monitoring and medical integration further enhances the capabilities of smart monitoring environments within the context of diet-related disease management.

1. ***RO-SmartAgeing system***: The RO-SmartAgeing system contributes a unique dimension by focusing on age-related factors and tailored interventions. Through the integration of this system, comprehensive monitoring extends beyond immediate health concerns to address the long-term impact of dietary choices on ageing. This holistic approach allows healthcare professionals to consider age-related factors in designing personalized diet-related disease management strategies;
2. ***NeuroPredict Platform***: The NeuroPredict Platform introduces advanced neuroinformatics to the comprehensive monitoring landscape. By integrating neurological data and predictive analytics, it offers insights into the intricate connections between brain health, dietary patterns, and overall well-being. This platform enables a more nuanced understanding of how neurological factors influence dietary habits and vice versa, enriching the overall data pool for a holistic health assessment;
3. ***HepatoConect system***: The HepatoConect system specializes in liver health monitoring and integration. Given the vital role of the liver in processing nutrients and metabolising substances, its integration into comprehensive monitoring is pivotal for diet-related disease management. This system provides real-time data on liver function, allowing healthcare professionals to tailor dietary recommendations with specific consideration for liver health, thereby optimising overall disease management strategies.

The design and development of our three RHMS are based on several common elements that we deemed fundamental for obtaining integrated insights and a patient-centred approach. As illustrated in Figure 3, starting from the implementation of these common elements, we developed an RHMS (RO-SmartAgeing System) and are currently developing two other RHMS (NeuroPredict Platform and HepatoConect System); each of them is tailored to be considered a novel evaluation method for specific diet-related disease management, as presented above.

Particularly distinctive is the notifications and alerts element, which is highly adapted for both patients and physicians, with early notifications resulting from data analysis that help with disease prevention and management. In terms of user contact, the user interface and communications element prioritizes an intuitive interface, secure communication channels, and personalized alerts, which include triggered alerts for critical scenarios. The framework comprises robust security protocols to provide complete data protection in the RHMS. The framework facilitates smooth integration with a range of medical devices.

The framework is further refined with our three tailored RHMS—RO-SmartAgeing System, NeuroPredict Platform, and HepatoConnect System—each with distinct capabilities designed to adapt to different diet-related conditions, allowing for customisation of functionalities based on the disorder's specifics, resulting in tailored diet-related disease management.

Integrating the tailored RHMS with the National Integrated Information System for Social Health Insurances has enormous potential and advantages for healthcare. This collaboration would ensure that health data flow seamlessly between the RHMS and the national health insurance system, improving overall healthcare delivery efficiency. The synergy between the tailored RHMS and the National Information System of Social Health

Insurances has the potential to establish a more connected, data-driven, reliable, and effective healthcare ecosystem.

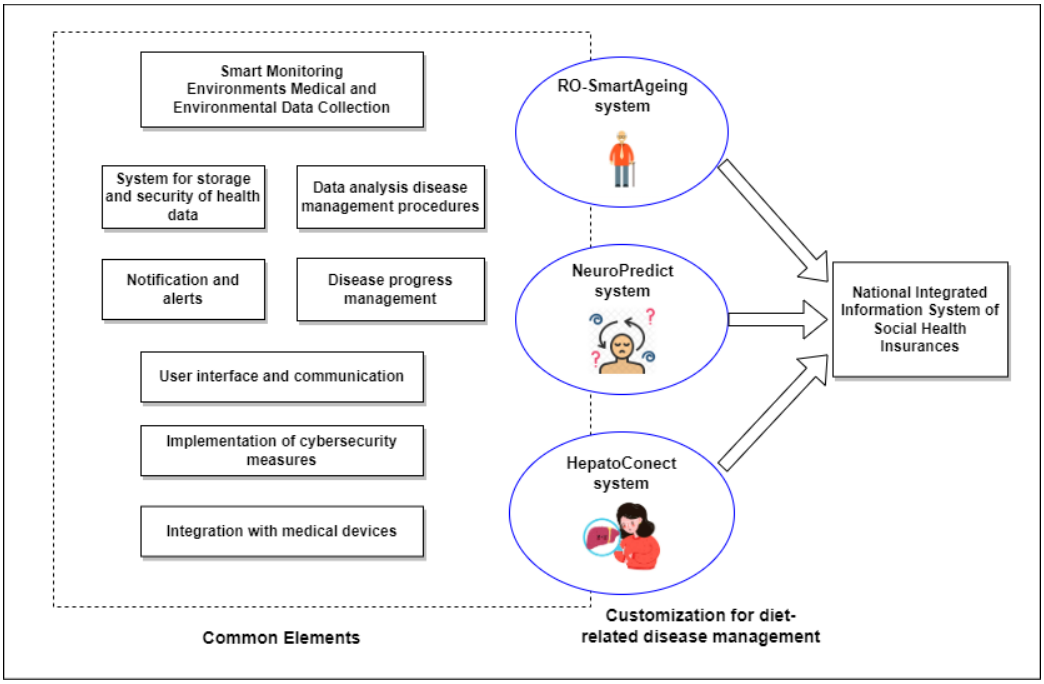

Figure 3. Integrated outline for the targeted RHMS: common elements and customisation for diet-related disease management.

The ***novelty*** related to the three RHMS is their innovative and adaptive capabilities that transform customized diet-related disease management. The RO-SmartAgeing system offers an integrated approach to tailored solutions that take into account the long-term influence of dietary choices on ageing, which is an advanced perspective in healthcare. The NeuroPredict Platform provides a better knowledge of the multifaceted connections between brain health, nutrition, and general well-being, bringing new insights to healthcare evaluations. The HepatoConect system focuses on liver health monitoring and offers real-time data for tailored dietary recommendations, distinctively optimising this disease management.

3. Perspectives and Outcomes of the Presented RHMS with a Focus on Diet-Related Approaches

Our tailored RHMS encompass various common foundational elements and functionalities, as illustrated in Section 2. The synergy and complementarity of the domains in which the authors of this paper operate (i.e., healthcare and IT), along with their research, have resulted in the design, development, and implementation of RHMS that can be adapted to provide reliable support for healthcare professionals in different fields of medical assistance. In this regard, this chapter presents relevant aspects of two of our tailored RHMS (HepatoConect system and NeuroPredict Platform) to highlight how the specifically implemented functionalities targeting dietary aspects directly associate and integrate into the personalized management of conditions such as LC and schizophrenia. Even though these two RHMS are currently under development, the results obtained from the implementation of the other RHMS, the RO-SmartAgeing system (currently in the testing phase in a clinical environment), support and demonstrate the comprehensive insights gained through the use of these RHMS, as well as the potential to achieve scalable and flexible smart solutions.

3.1. Optimising Nutrition Interventions in Liver Cirrhosis

3.1.1. Aspects of Nutrition in Liver Cirrhosis—Pathophysiology and Recent Insights

Malnutrition is present in 20% of patients with compensated LC and more than 50% of patients with decompensated liver disease at diagnosis and acts as an independent predictor of low survival [115]. The classical phenotype of malnutrition in LC is muscle wasting and loss of muscle mass (i.e., sarcopenia), but adipose tissue depletion may also occur, especially in patients with alcohol abuse and in women. Frailty, defined as loss of functional and cognitive capacity leading to a vulnerable state, is also considered a nutrition-related disorder, while deconditioning, a deterioration of muscle functional capacity secondary to sarcopenia and immobility is a hallmark of any chronic debilitating disease, including LC.

There is a bidirectional relationship between nutritional status and decompensating events in LC—poor dietary management and malnutrition, especially sarcopenia, increase the risk of decompensation [116]—while each decompensating event is associated with a hypercatabolic state and altered nutritional intake (infections, gastrointestinal bleeding, altered mental status, dietary restrictions due to medical interventions, etc.), contributing to significant denutrition, which further leads to increased morbidity and mortality.

Although malnutrition predominantly refers to undernutrition, obesity is increasingly observed in newly diagnosed LC as a result of the growing incidence of LC cases related to MASLD and may mask the underlying muscle mass depletion, further contributing to higher morbidity and mortality [117].

Encouraging weight loss without a prior nutritional evaluation and overlooking the need for a personalized nutritional intervention in these patients may have a rather negative impact on their prognosis. As an emerging entity, novel nutrition evaluation methods and nutrition intervention strategies need to be implemented, as further research should focus on managing sarcopenic obesity and its associated metabolic comorbidities.

Whether malnutrition can be reversed in LC patients is controversial, but there is certainly a need to improve the dietary intake of these patients, avoiding restrictions that are not evidence-based and encouraging health-promoting practices, including personalized diet optimisation and increased physical activity.

The pathophysiology of malnutrition in LC is complex, and some aspects regarding nutritional intervention are still debatable. The liver plays a central role in the metabolism of carbohydrates, proteins, fat, vitamins, and minerals. Alterations in substrate utilisation for energy production are a main feature of LC and consist of depleted hepatic glycogen storage and impaired hepatic glycogenolysis, increased fat oxidation, and increased protein catabolism, resulting in protein-energy malnutrition even from the early stages of the disease. In addition, portal hypertension leads to malabsorption through impaired gut motility, intestinal dysbiosis, intestinal oedema, and mucosal changes. Evidence suggests recommending a high-energy and protein-rich diet (>1.2 g/kg/day) divided into three main meals and three snacks, the late-evening snack consisting of slow-release carbohydrates and proteins being the most important and most effective in improving nutritional status, risk of complications and mortality rates [118].

The use of branched-chain amino acid (BCAA) supplementation shows promise in reducing the risk and severity of hepatic encephalopathy but is limited by poor palatability and the need for further exploration of dietary manipulation for optimal BCAA disponibility [119]. Evidence is also accumulating that high-quality protein intake should not be restricted in patients with hepatic encephalopathy due to the subsequent risk of protein-energy malnutrition. Moreover, optimising the intake of fermentable fibre would reduce the absorption of intestinal ammonia in a way similar to supplementation with lactulose would and also contribute to maintaining a relatively stable glycaemic response [120]. Alterations in glycaemic homeostasis consisting of pre-existing diabetes mellitus type 2 (usually as a component of metabolic syndrome) and the newly acknowledged hepatogenous diabetes, as a distinct form of diabetes occurring after cirrhosis onset, are associated with poor outcomes and increased risk and severity of LC complications [121].

According to the European Association for the Study of the Liver (EASL)'s recommendations on nutrition in chronic liver disease, there is sufficient evidence to support the healthy eating of a variety of unprocessed nutrients, as no food other than alcohol causes direct liver damage. Eating an adequate amount of calories is of greater importance than avoiding some foods and limiting nutrient intake. Previous recommendations regarding a strict limitation of salt intake are considered to significantly decrease food palatability and negatively impact nutrient consumption, with the limited beneficial impact on health underweighting the negative impact on nutritional status [122]. However, patients need to be educated to avoid ready-to-eat and processed foods with high concentrations of sodium and instead consume healthy home-based meals with controlled salt flavouring.

Nutritional Status Evaluation

Malnutrition is one of the most common and potentially reversible complications of LC and increases the risk of morbidity and mortality. All patients with chronic liver impairment and, in particular, patients with decompensated LC should undergo nutritional assessment to confirm the presence and determine the severity of malnutrition so that personalized interventions can be promptly instituted.

The lack of validated rapid screening tools and constant challenges in interpreting body composition and laboratory results in the presence of volume overload and liver dysfunction are the main reasons why nutritional screening and assessment are not routinely performed in patients with LC [123].

For all patients, especially for those at risk of malnutrition, a detailed nutritional assessment is required and typically includes physical examination, assessment of additional risk factors like smoking and alcohol consumption, laboratory testing for macro- and micronutrient deficiencies, global assessment tools for frailty and deconditioning, and body composition testing. Recent weight loss, loss of appetite, nausea, altered taste or smell, abdominal distension and/or pain, altered intestinal transit, and specific signs and symptoms of vitamin deficiency should be routinely assessed and, if present, should trigger immediate intervention to prevent further denutrition.

The most accessible but imperfect screening tool for malnutrition in LC is the body mass index (BMI), derived from a combination of anthropometric indices (height and weight in kg); a value of <18.5 kg/m^2 and the classification of LC as class C (the most severe) according to the Child–Pugh classification should immediately trigger additional nutritional screening [124]. However, in patients with sarcopenic obesity (in whom excess adipose tissue may mask the underlying loss of muscle mass) and in patients with volume overload (ascites and oedema), the BMI is suboptimal in determining the nutritional status, as it does not provide information regarding body mass composition and lean body mass.

Determining muscular mid-arm circumference and tricipital skinfold thickness are alternative rapid tools to determine weight and muscle loss, but the optimal methods for body composition analysis are cross-sectional imaging (including computed tomography or magnetic resonance imaging) and bioelectrical impedance analysis. Cross-sectional imaging is currently the gold standard for the evaluation of sarcopenia [125], as it allows for direct and standardized assessment of muscle mass (through skeletal muscle index or psoas muscle index), being especially useful in patients with sarcopenic obesity.

3.1.2. Potential of RHMS (HepatoConect System) Capabilities for Liver Cirrhosis Management: Telenutrition, Nutrition Intervention, and Education Strategies

Innovations in digital health should play a key role in standardising the management of liver disease and eliminating potential quality gaps. Although efforts have been made to develop quality standards of care for patients with this condition, there are still wide variations in clinical practice. Moreover, nutritional evaluation and nutrition intervention are extremely important but poorly addressed aspects of the management of LC.

The American Association for the Study of Liver Disease developed a series of measures to improve the quality of care for patients with LC in the management of ascites,

oesophageal varices, hepatic encephalopathy, screening for hepatocellular carcinoma, and evaluation for liver transplantation [126]. However, some studies show that less than one-third of patients with LC receive all the recommended care for ascites [127], and even fewer patients receive all the care needed for the screening and management of gastroesophageal varices [128].

The HepatoConect system can effectively address the unmet needs in the care of patients with LC by expanding the access of rural communities to healthcare, providing health education, encouraging preventive measures, and increasing compliance with treatment and screening, all leading to patient empowerment and improved quality of life. Lately, various eHealth programs have been piloted, aiming to ensure the early detection of decompensation in LC patients and allow for early remote interventions. The use of remote tools for monitoring vital signs, together with educational programs for patients and caregivers, demonstrate the potential to improve symptom control and prevent the onset of decompensation, but available studies show a high level of heterogeneity when considering patient characteristics, types of devices used for remote monitoring, and definition of outcomes [129].

To overcome these disparities, the HepatoConect system offers a multitude of health monitoring possibilities, from intelligent watches and sleep monitoring to vital parameters recording and diet tracking facilities, intending to aid clinicians in tailoring their medical interventions for the personalized needs of patients with different stages of liver impairment.

Education Strategies

Educating patients and their caregivers about the complications of LC and their preventive measures is crucial to increasing the duration and quality of life; therefore, it is carefully addressed in the HepatoConect system.

Well-documented barriers include the complexity of the disease, comorbid conditions, and medication difficulties (on the one hand, the large number of medications that need to be administered and, on the other hand, the necessity of titrating them according to blood pressure, pulse, diuresis, weight, etc.). Effective patient education interventions are few, and those that are available are mainly aimed at educating healthcare staff and/or caregivers, focusing predominantly on complex definitions and nursing principles [130]. Multiple studies have proven that educating patients through simple methods, with a focus on illustrations, accessible language, and other patients' testimonials or support groups, produces a significant improvement in disease management and quality of life scores, as well as reducing fatigue, anxiety, and abdominal symptoms [131–133].

A less encouraging study has shown that more than 50% of patients cannot provide a clear definition of LC, its long-term complications, or signs of worsening disease [134]. Several questionnaire-based studies assessing the educational needs of patients with chronic liver disease concluded that more than 85% were highly interested in learning about their disease, with those with more hospital visits showing the highest interest, which could also partly be explained by a higher level of compliance [135]. Another recent study on patients hospitalized for a complication of LC found that 79% were interested in using a digital health management tool that could provide information about their disease, and 75% considered an educational intervention concerning a necessary low-salt diet, citing that this would increase their compliance and engagement with healthy food selection [136]. Moreover, education interventions consisting of nutritional counselling through in-person visits and a guide booklet, combined with continuous telemonitoring over 6 months, had a significant impact on quality of life, ascites, oedema, and hospital admission rates in LC patients [137].

Nutrition Evaluation Methods from an RHMS (HepatoConect System) Perspective

From an RHMS perspective, such as that of the HepatoConect system, dietary intake can be monitored using a 24-h dietary recall or a 3-day food intake diary. Both rely on

patient's cooperation and may be difficult to implement in those with advanced disease and cognitive impairment, but novel evaluation methods integrated into the HepatoConect system, with user-friendly interfaces for high compliancy allow for effortless daily monitoring of diet and nutritional supplementation, as recalled by the patient or by their caregivers. The continuous monitoring of dietary intake further allows for prompt interventions regarding diet optimisation, thus limiting, as much as possible, prolonged fasting periods or poor nutritional intake, as both significantly impact survival.

As previously mentioned, frailty is strongly associated with malnutrition, disability, and deconditioning in patients with advanced LC. The liver frailty index, composed of three performance-based tests (grip strength, chair stands, and balance), is an in-person tool specifically developed for patients with LC to objectively determine physical function [138]. As a novel evaluation method, a virtual telemedicine-enabled frailty assessment tool for patients with advanced LC was recently developed. The tele-liver frailty index (TeLeFi), consisting of validated functional capacity surveys and virtually-assessed chair stands, was able to accurately identify frailty in liver transplant patients via telemedicine when compared to ambulatory frailty testing [139] and may be used on a large scale as a screening tool to diagnose frailty or to perform follow-up to identify those in greatest need of additional interventions for maintaining functional independence. In this context, the HepatoConect system also incorporates telemedicine-enabled frailty assessment tools and further evaluation methods based on the patient's performance status.

Considering these findings and the spectrum of liver disease, as well as its progressive nature, the HepatoConect system can address multiple needs in the form of a two-faceted intervention approach, which may also act as a two-step intervention:

1. Targeted education strategies, personalized nutritional assessment, and dietary interventions in patients with obesity and MASH, with or without compensated advanced chronic liver disease, who may be at risk of decompensation and malnutrition (both over- or undernutrition), aiming to prevent decompensation by limiting disease progression through early health interventions and lifestyle changes;
2. Targeted education strategies (both for patients and caregivers), personalized nutritional assessment, and dietary interventions combined with continuous telemonitoring for patients with advanced or end-stage liver disease, aiming to proactively manage any decompensating event and improve nutritional status and quality of life, as well as prevent hospitalisation and/or institutionalisation.

3.1.3. RHMS Role (HepatoConect System) for Optimising Nutritional Support for Liver Cirrhosis

As detailed above, the HepatoConect system is designed as a remote health monitoring tool for optimising nutritional status evaluation and intervention and improving outcomes in LC patients at risk for decompensation.

Table 1 summarizes the functionalities of the HepatoConect system, with a focus on potential nutritional evaluation, monitoring, and intervention capabilities.

Table 1. Characteristics of different nutritional status evaluation and intervention methods and specific actual and future capabilities of the HepatoConect system.

Type of Evaluation and Intervention Method	Characteristics and Requirements	Specific Capabilities of the HepatoConect System
Physical examination	- Initial physical examination should be performed during a medical visit	- Video teleconsultation
BMI, TSF, MAMC, and BIA	- TSF and MAMC are quick methods unaffected by fluid retention but have interobserver variability; weight and BIA are affected by fluid retention - Useful for weight loss management in overweight patients	- Daily weight monitoring and automatic calculation of BMI through the Withings Body+ scale that incorporates BIA - Provides evolution trends for easy interpretation

Table 1. *Cont.*

Type of Evaluation and Intervention Method	Characteristics and Requirements	Specific Capabilities of the HepatoConect System
Frailty assessment	- Important for identifying those at high risk for malnutrition and adverse events - Classically requires a standard in-person assessment method	- Functional capacity surveys and virtually assessed performance measures * - Aids in tailoring nutritional intervention
CT scan and MRI	- Gold standard for direct assessment of muscle mass - Radiation exposure (CT); high costs and low availability (MRI)	- Image integration and interpretation through AI *
Dietary intake assessment and intervention	- 24 h dietary recall or 3-day food intake diary - Implies patient/caregiver compliance and permanent monitoring	- Use of standard/personalized questionnaires and immediate personalized diet optimisation intervention (either as automated response or through medical intervention) - Generates alerts in case of prolonged unplanned fasting periods and "late-night snack" reminders - Continuous reassessment of nutritional goals + reinforcement strategies via reminders if goals not targeted
Physical activity tracking	- Important for preventing sarcopenia and deconditioning in LC patients - Important intervention for weight loss support in overweight patients - Implies patient compliance	- Withings Move ECG smartwatch-enables step counting, walking distance, and burned calories - Permanent monitoring of trends and reinforcement strategies for weight loss or frailty prevention
Bowel movement tracking	- Implies patient/caregiver compliance	- Comprehensive daily questionnaire-based assessment including virtual stool charts - Sends notifications for personalized intervention (like diet optimisation or lactulose supplementation)
Education intervention	- Crucial for patient empowerment and increased quality of life - Should be tailored for the stage of liver impairment and level of literacy - Not limited to nutrition education	- High-access digital resources - Tailored interventions through video consultation for additional counselling based on medical history and telemonitoring data

* Future capabilities of the HepatoConect system: integration of virtual frailty assessment tools; integration of AI and DL algorithms for cross-sectional imaging data interpretation. BMI = body mass index; TSF = tricipital skinfold thickness; MAMC = mid-arm muscle circumference; BIA = bioelectrical impedance analysis; CT = computer tomography; MRI = magnetic resonance imaging; AI = artificial intelligence; LC = liver cirrhosis; ECG = electrocardiography.

Table 2 presents other components of a telemonitoring intervention with focus on LC management and targeted functionalities of the HepatoConect system.

Table 2. Targeted actual and future functionalities of the HepatoConect system with a focus on LC management.

Targeted Functionalities of the HepatoConect System	Brief Presentation	Characteristics and Requirements
Medical history recording	- Enables assessment through teleconsultation - Provides organized electronic personal health records, and rapid access to complete medical history including prescriptions and previous medical interventions, - Comprises advanced applications based on HepatoConect database	- Can be partially gathered by nonmedical staff or caregivers

Table 2. *Cont.*

Targeted Functionalities of the HepatoConect System	Brief Presentation	Characteristics and Requirements
Sign and symptom evaluation	- Includes easy-to-fill sign and symptom questionnaires and body temperature monitoring tool - Triggers alerts for acute sign and symptom management	- Required smart device: Withings Thermo - Needs patient/caregiver cooperation for symptom reporting
Ascites management	- Triggers alerts in case of rapid weight gain in consecutive days - Enables interventions like a reduction in salt intake, increase in diuretic dose, and monitors weight loss patterns to determine the need for additional interventions	- Crucial for improvement in nutritional status - Reduces the risk of SBP and HRS, and early intervention may eliminate the need for paracentesis - Required smart device: Withings Body+
Early detection of HE	- Includes sign and symptom-based evaluation and a validated neurophysiologic screening test for detection of overt HE - Triggers immediate intervention (either dietary intervention, BCAA supplementation or lactulose administration)	- Crucial for early intervention and prevention of HE - Intricated with age-related cognitive impairment, alcohol use, certain medications, or sleep apnoea (daytime sleepiness) - Needs patient/caregiver cooperation for symptom reporting
Heart rate and blood pressure monitoring	- Enables heart rate monitoring and one-lead ECG with feature of AF detection - Includes blood pressure monitor	- Crucial for beta-blocker titration and early detection of complications (hypotension, bradycardia or arrhythmia) - Required smart devices: Withings BPM Core, Withings Move ECG
Continuous glucose monitoring *	- Integrated noninvasive glucose monitoring devices and personalized alarm features for prompt intervention - Enables personalized dietary and medical interventions for patients with T2DM	- Crucial for diabetic patients - Advanced LC predisposes to hypoglycaemia and potentially fatal complications
Sleep monitoring	- Enables sleep pattern monitoring and interpretation and sleep apnoea detection - Offers the possibility for personalized intervention	- Offers important data about sleep patterns and tracks sleep-wake rhythm disturbances as a potential indicator of early HE - Required smart device: Withings Sleep Analyzer
Medication adherence monitoring	- Tracks medication adherence, adverse effects, or supplements intake - Keeps evidence of substance and dosage changes and enables remote personalized interventions based on telemonitoring data - Generates medication reminders	- Crucial for optimal disease control - Increases adherence to prescribed treatment - Needs patient cooperation for symptom and supplement use reporting
Alcohol use detection *	- Enables continuous alcohol consumption monitoring through wearable biosensors	- Aids in inducing and maintaining alcohol abstinence - Useful in LC patients awaiting liver transplant to confirm alcohol abstinence - Needs patient acceptance

* Future functionalities of the HepatoConect system through acquisition and integration of specific sensors in the HepatoConect smart monitoring environment. SBP = spontaneous bacterial peritonitis; HRS = hepatorenal syndrome; HE = hepatic encephalopathy; BCAAs = branched-chain amino acids; ECG = electrocardiography; AF = atrial fibrillation; LC = liver cirrhosis; T2DM = type 2 diabetes mellitus.

3.2. Schizophrenia, Dietary Habits, and Physical Health

3.2.1. Link between Schizophrenia, Dietary Habits, and Physical Health

Because of the complex interplay between medication and lifestyle decisions, people with schizophrenia tend to have an increased chance of developing metabolic syndrome [140]. Although the adverse effects of antipsychotic medications on obesity and problems with the metabolism of carbohydrates in patients with schizophrenia are well established, weight increase is seen even before the start of medication, indicating the important role that lifestyle decisions play.

Schizophrenia patients, in comparison with the general population, exhibit inadequate nutritional choices: high daily energy consumption, a substantial intake of animal fats,

and a lower intake of vegetable fats. This dietary pattern is linked to higher inflammatory markers, potentially contributing to metabolic syndrome development. Global patterns indicate that countries with a higher total intake of dietary fat, particularly saturated fat from land animals, have a higher prevalence of schizophrenia [141]. Additional findings show that a significant percentage of schizophrenia patients have fast eating habits [142], low fruit and fish consumption, and various nutrient deficiencies [143].

Out of all the metabolic abnormalities associated with schizophrenia, obesity, and dyslipidaemia appear to have the greatest negative consequences on cognitive function. Diffuse brain alterations may be independently associated with obesity in the early phases of this disorder. In metabolic syndrome patients, there appears to be a correlation between poor eating practices and the degree of negative symptoms. One study found that individuals with schizophrenia had lower cognitive function when their negative and general symptoms were more severe [144]. Research also suggests that people who experience extreme negative symptoms have significant impairments in their working memory, indicating that the affected individuals have a larger chance of acquiring cognitive impairment over time if their diet quality remains unchanged and their negative symptoms do not improve.

Schizophrenia significantly affects physical health as well, considering the compelling link between this psychosis and the heightened risk of various physical health issues. Among the prominent concerns is an increased susceptibility to cardiovascular risks, such as hypertension, atherosclerosis, and coronary heart disease, compared to the general population. Additionally, these individuals are at a greater risk of developing diabetes mellitus [145] and respiratory diseases [146].

The interplay between schizophrenia, dietary habits, and physical health is intricate and multifaceted. Lifestyle factors, including diet, contribute significantly to the overall well-being of individuals with schizophrenia. Poor dietary choices, such as high consumption of saturated fats and inadequate intake of essential nutrients, may not only exacerbate the symptoms of schizophrenia but also contribute to the development of physical health issues. The relationship between mental health and diet is bidirectional, as the symptoms of schizophrenia can influence an individual's dietary habits. Understanding this complex interplay is essential for developing comprehensive interventions that address both mental and physical aspects of health in individuals with schizophrenia.

As the complex landscape of schizophrenia is more and more investigated, it becomes increasingly apparent that there is a critical relationship between this mental illness and eating patterns. The connection between these elements transcends mere coincidence, offering a compelling avenue for understanding the holistic health profile of individuals grappling with schizophrenia. Therefore, one of the nonpharmacological strategies that can be used to help individuals living with schizophrenia improve their overall health is dietary management.

The urgency of comprehending the holistic impact of schizophrenia can be done through innovative approaches to management, particularly with the integration of RHMS, like the NeuroPredict Platform, which holds promise in revolutionising how to perceive, monitor, and intervene in the lives of individuals living with schizophrenia by bridging the gaps and providing real-time insights into the dynamic interplay between schizophrenia, dietary habits, and physical health.

Despite significant progress in understanding the connections between schizophrenia—diet—and physical activities, there are currently notable gaps and areas of uncertainty. One critical gap lies in the limited exploration of the specific mechanisms through which dietary habits impact the onset and progression of schizophrenia. Understanding these mechanisms is essential for developing targeted interventions. Additionally, there is a need for more research on the long-term effects of dietary interventions on the mental and physical health outcomes of individuals with schizophrenia.

3.2.2. RHMS Role (NeuroPredict Platform) in Managing Schizophrenia

Through its innovative features, the NeuroPredict Platform is a cutting-edge RHMS, offering a paradigm shift in the management of schizophrenia. NeuroPredict seamlessly integrates a variety of sensors and devices strategically positioned to collect and transmit crucial health data to a centralized web platform. Moreover, with its user-friendly interface and advanced analytics, it emerges as a pivotal tool in the comprehensive management of schizophrenia, ensuring a holistic approach that extends beyond conventional pharmacotherapy.

Real-time data obtained through the NeuroPredict Platform serve as game-changers in the monitoring and management of schizophrenia. The immediacy of data transmission allows healthcare professionals to detect subtle changes in a patient's condition promptly. Early detection is crucial in schizophrenia management, as it facilitates timely interventions to prevent the escalation of symptoms or potential relapses. The platform's ability to deliver real-time insights into medication adherence ensures that adjustments can be made promptly if necessary. Healthcare providers can proactively address emerging issues, optimize treatment plans, and personalize interventions based on the individual's evolving health profile. The NeuroPredict Platform, thus, fosters a dynamic and responsive approach to schizophrenia management, promoting improved outcomes and a higher quality of life for individuals living with this complex mental health disorder.

Schizophrenia may influence numerous factors including physiological measures (heart rate variability (HRV), blood volume pulse, blood pressure, skin temperature, electromyography, or cortisol levels) and behavioural data, which may include sleep-related features, daily activities, or voice characteristics. As a result, gathering behavioural and medical data has been widely used for general mental health management and monitoring. The transformation of raw sensor data into markers of mental health-related behaviours and states involves converting the collected data into features; machine learning (ML) models are then employed to define behavioural markers based on these features. Smart devices, such as smartwatches, serve to passively monitor behaviour by detecting location, acceleration, or social activities.

Notably, in the realm of schizophrenia, physiological sensing, particularly the measurement of HRV data as an indicator of decompensation, has shown promising outcomes in monitoring this condition. In addition, individuals with schizophrenia exhibit a correlation between reduced GPS mobility, heightened negative symptom severity, and motivational deficits.

In the context of the NeuroPredict Platform, the management of schizophrenia can be addressed in relation to the smart components that NeuroPredict integrates:

1. **Diet:** Understanding the intricate relationship between dietary choices and schizophrenia risk requires sophisticated technological tools. The glycemia sensor, a device designed to monitor blood glucose levels, becomes a key player in unravelling the impact of dietary decisions on blood sugar regulation. Given the emerging link between diabetes and schizophrenia in certain studies [147], continuous monitoring of glucose levels provides valuable insights. Additionally, the smart body scale serves as a comprehensive tool for tracking changes in weight and body composition. This not only offers insights into nutritional status but also acts as an indicator of dietary habits and potential metabolic influences on mental health. The continuous monitoring of these physiological markers contributes to a more nuanced understanding of the interplay between diet and schizophrenia risk. Diet monitoring within the NeuroPredict Platform for patients with schizophrenia could have a significant impact on their disease management and overall health. Several effects that can intervene in this process may be, as follows:
    a. *Personalisation of nutritional interventions*: By monitoring eating habits, the NeuroPredict Platform can provide detailed data on patients' dietary preferences. This would enable the customisation of nutritional interventions, providing spe-

cific recommendations to correct nutritional deficiencies and improve overall diet quality;

b. *Weight and metabolism management*: The obtained data can contribute to the monitoring and management of patients' weight. Early identification of changes in eating habits can help prevent uncontrolled weight gain associated with schizophrenia and pharmacological treatment. In addition, information on caloric intake and macro- and micronutrient composition can be used to optimize patients' metabolism and reduce the associated risk of metabolic syndrome;

c. *Education and awareness*: By providing real-time information about diet quality through the NeuroPredict Platform, patients can be educated and encouraged to make healthy food choices. This could help improve their perception of food and raise awareness of the link between food and mental health;

d. *Symptom management*: Balanced and nutritious diets can influence mental well-being. By tracking consistency in adopting healthy eating habits, the NeuroPredict Platform can help medical practitioners manage if there is any correlation between dietary changes and the intensity of schizophrenia symptoms.

Dietary monitoring within NeuroPredict could not only provide a more detailed understanding of the nutritional factors influencing the health of patients with schizophrenia but could also provide valuable tools for personalising interventions and improving overall disease management.

2. **Sleep patterns:** The intricate dynamics between sleep patterns and mental health, particularly in the context of schizophrenia, necessitate advanced technological interventions. Sleep disruption is a significant issue for those who suffer from schizophrenia, with as many as 80% of individuals with schizophrenia being reported to have insomnia [148]. The Withings Sleep Analyzer emerges as a critical tool in this domain, monitoring and analysing sleep patterns to underscore the fundamental importance of adequate sleep in maintaining mental well-being. Complementing this, the smartwatch, with its capability to track overall health metrics, becomes invaluable. Observing changes in sleep patterns and activity levels through this device provides relevant indicators for ongoing mental health monitoring, offering a comprehensive approach to understanding and managing this disorder through technology.
3. **Stress:** Stress, a recognized exacerbating factor in schizophrenia symptoms [149], takes centre stage in mental health monitoring. The stress ring, designed to measure stress levels, offers a quantitative understanding of emotional well-being. By providing valuable data on stress levels, this technology enables a more comprehensive approach to managing schizophrenia. The ability to quantify stress adds a crucial dimension to the holistic care of individuals with schizophrenia, highlighting the significance of stress monitoring in the context of mental health.
4. **Alcohol consumption:** The complex interplay between alcohol consumption and mental health [150], especially in individuals with schizophrenia, demands meticulous attention. The medical blackbox integrated into the NeuroPredict Platform is equipped with alcohol detection capabilities, which are indispensable tools for monitoring substance use. Given the heightened vulnerability of individuals with schizophrenia to substance abuse, particularly alcohol, continuous monitoring of alcohol intake emerges as a vital component of holistic mental healthcare.
5. **Temperature monitoring:** Monitoring general health, as indicated by changes in body temperature, introduces an additional layer to mental health assessment [151]. The Withings smart thermometer, a tool capable of monitoring body temperature, becomes a valuable asset in this context. Detecting temperature variations provides insights into potential physical health issues that may impact mental health. By incorporating temperature monitoring into the array of health data, a more holistic understanding of an individual's well-being is achieved.

The integration of health data from various devices through platforms like NeuroPredict represents a paradigm shift towards a holistic understanding of physical and

mental health. The NeuroPredict Platform, by combining data related to diet, sleep, stress, and other factors, offers a nuanced and interconnected overview of an individual's well-being. This integrated approach enhances our ability to comprehend the intricate interplay of various elements in the context of schizophrenia. By synthesising diverse data streams, healthcare professionals gain a more comprehensive understanding of the multifaceted factors influencing mental health, paving the way for more informed and personalized interventions.

The application of advanced data analytics takes personalized health interventions to a new level, especially for individuals with schizophrenia. These interventions go beyond conventional approaches and encompass a spectrum of factors, such as diet, sleep hygiene, stress management, and substance use. By leveraging data-driven insights, healthcare professionals can tailor interventions to address the unique needs and challenges of each individual. This personalized approach acknowledges the heterogeneity of schizophrenia and underscores the importance of individualized strategies for effective and sustainable mental healthcare.

In the evaluation of schizophrenia management, the integration of novel evaluation methods becomes a cornerstone of progress. Utilising advanced techniques, the impact of NeuroPredict on diet management in schizophrenia can be assessed with a high degree of precision. This involves not only tracking eating habits, body-related parameters, or symptom severity but also evaluating medication adherence and overall functional outcomes. By adopting a comprehensive approach, healthcare professionals can gauge the effectiveness of integrated health technologies in the context of schizophrenia care and personalize a diet based on the patients' behaviour. The use of sophisticated evaluation methods provides valuable insights into the real-world impact of interventions, facilitating continuous refinement and optimisation of strategies for enhanced patient outcomes.

When it comes to data management, the data acquired from the NeuroPredict Platform play a pivotal role in the effective control of schizophrenia by offering valuable insights into various facets of an individual's health. In the realm of diet management for schizophrenia patients, NeuroPredict data can be leveraged in the following ways:

- *Dietary patterns and nutrition monitoring*: Utilizing NeuroPredict to monitor dietary patterns and nutritional intake, providing insights into the individual's eating habits. Tracking the consumption of specific nutrients, including key micronutrients, helps in assessing whether dietary choices align with recommended nutritional guidelines for schizophrenia patients;
- *Meal regularity assessment*: leveraging NeuroPredict data can help in analysing the regularity of meals and eating schedule as irregular eating patterns may influence both physical health and the effectiveness of schizophrenia management strategies;
- *Real-time dietary feedback*: The NeuroPredict Platform can integrate features that provide real-time feedback on dietary choices. This could include reminders or notifications encouraging healthier food choices and adherence to a balanced diet;
- *Nutrition education resources*: The NeuroPredict Platform can deliver educational resources related to nutrition and dietary choices specific to schizophrenia management. This empowers individuals with information to make informed decisions about their dietary habits;
- *Dietary adherence and symptom correlation*: Correlations between dietary adherence and symptomatology can be explored through the NeuroPredict Platform. Understanding how dietary choices may relate to the severity of symptoms provides valuable information for both individuals and healthcare providers, helping in the management of this disease;
- *Medication adherence monitoring*: The NeuroPredict Platform can diligently track medication adherence through reminders and notifications. By analysing patterns of medication adherence, healthcare providers gain a comprehensive understanding of the treatment plan's effectiveness, enabling necessary adjustments as needed;

- *Sleep patterns and quality monitoring*: The monitoring of sleep patterns becomes instrumental in identifying disruptions, a common occurrence in individuals with schizophrenia, enhancing sleep hygiene;
- *Activity and movement tracking*: Harness NeuroPredict Platform capabilities to monitor daily activities and movement patterns. Changes in activity levels provide valuable insights into the individual's overall well-being and mental state, aiding in a holistic approach to schizophrenia management;
- *Stress level monitoring*: Some NeuroPredict Platform devices feature stress tracking capabilities. The continuous monitoring of stress levels assists healthcare providers in understanding triggers and developing targeted strategies for stress management, a particularly relevant aspect of schizophrenia care;
- *Social interaction assessment*: The NeuroPredict Platform data offer insights into social interactions through communication patterns, interaction frequency, and engagement with social activities. Changes in social behaviour can serve as indicators of the individual's mental health, enriching the assessment process;
- *Physiological measurements*: Integrate physiological measurements, such as HRV and skin conductance, into the NeuroPredict Platform. These metrics provide additional information about the individual's autonomic nervous system and stress response, contributing to a more comprehensive health profile;
- *Environmental triggers analysis*: The NeuroPredict Platform may include sensors to detect environmental factors like noise levels and ambient light. Analysing these data points helps identify potential environmental triggers impacting mental health, contributing to a more holistic understanding of schizophrenia triggers;
- *Mood and symptom tracking*: Incorporating features allowing individuals to log their moods, symptoms, or perceived stress levels directly into the NeuroPredict Platform. This self-reported data complement objective measurements, contributing to a more nuanced understanding of the individual's mental health.

Being a neuropsychiatric syndrome, schizophrenia exhibits a range of symptoms encompassing psychotic features like delusions and hallucinations, negative aspects such as diminished motivation and blunted affect, and cognitive difficulties including attention deficits, working memory issues, verbal fluency challenges, and various problems in social cognition. Acknowledging the imperative for improved management, there is a growing recognition of the significance of continuous remote monitoring through the help of RHMS solutions, such as the NeuroPredict Platform. This involves identifying both subjective and objective markers to detect signs of psychotic relapse, aiming for more effective control over conditions within the schizophrenia spectrum.

3.2.3. Potential of the NeuroPredict Platform's Capabilities for Schizophrenia Management: ML for Personalized Interventions

ML for predictive analytics in the context of schizophrenia involves utilising advanced algorithms to analyse data from the NeuroPredict Platform over an extended period. This approach is particularly valuable, as it aims to identify patterns and trends that may precede relapses or symptom exacerbations in individuals with schizophrenia.

Schizophrenia is characterized by its complex and often unpredictable nature. Predictive analytics through ML provides a forward-looking perspective by discerning subtle changes and patterns within the data collected through RHMS based on early interventions, individualized treatment plans, enhanced patient engagement, and longitudinal monitoring.

ML for predictive analytics in schizophrenia management is a forward-thinking approach that leverages the power of data analysis to anticipate changes in an individual's condition. By identifying predictive patterns, healthcare providers can intervene early, tailor treatment plans, and enhance overall care for individuals living with schizophrenia. In the context of the NeuroPredict Platform, predictive analytics is based on the following:

- *ML algorithms*: Within the NeuroPredict Platform, ML algorithms serve as sophisticated tools that can autonomously analyse extensive sets of historical data. These

algorithms are designed to identify intricate patterns and relationships within the data, allowing the system to learn from past behaviours and responses;

- *Data types*: The data subjected to ML analysis span various dimensions relevant to schizophrenia management. This includes but is not limited to records of medication adherence, sleep quality metrics, physiological responses such as HRV, and indicators of social interactions. Each data type holds crucial insights into the individual's well-being and mental health status;
- *Historical data*: The ML analysis involves the examination of historical data accumulated over an extended period. This longitudinal approach enables the algorithms to capture trends, fluctuations, and dependencies that may be indicative of the individual's unique patterns of response and behaviour;
- *Pattern recognition*: One of the primary objectives of ML analysis is pattern recognition. The algorithms discern recurring sequences or anomalies within the historical data, uncovering connections that may not be immediately apparent through conventional analysis. For instance, the system can identify correlations between variations in sleep quality and subsequent changes in medication adherence or physiological responses;
- *Medication adherence patterns*: In the context of schizophrenia management, the ML analysis pays particular attention to medication adherence patterns. By scrutinising historical records, the system can identify consistent trends or irregularities in the individual's adherence to prescribed medications. This insight is invaluable for understanding the impact of medication on symptom management;
- *Sleep quality insights*: The analysis also encompasses sleep quality metrics, shedding light on the individual's sleep patterns over time. This information is vital, as disturbances in sleep are often linked to exacerbations of schizophrenia symptoms. Understanding these patterns can inform interventions related to sleep hygiene and contribute to proactive management;
- *Physiological responses and social interactions*: ML algorithms delve into physiological responses, such as HRV, and indicators of social interactions. By recognising subtle shifts in these parameters, the system can infer potential stressors, triggers, or changes in the individual's mental health state.

In essence, the ML analysis within the NeuroPredict Platform is a comprehensive exploration of historical data, unveiling hidden insights and patterns that contribute to a nuanced understanding of the individual's mental health journey. This analytical capability forms the foundation for subsequent applications, such as predictive analytics and personalized interventions, enhancing the system's effectiveness in supporting schizophrenia management.

A possible use case of an application (Figure 4) which aligns with the broader trend in healthcare towards precision medicine and personalized approaches to mental health and diet management may be considered by integrating the following steps:

1. **ML analysis**: The NeuroPredict Platform employs ML algorithms to analyse diet-related data (nutritional intake, meal regularity, nutrient profiling, dietary preferences, or correlated caloric intake with physical activities), historical and medications or sleep-related data over an extended period, identifying patterns related to medication adherence, sleep quality, physiological responses, and social interactions.
2. **Predictive analytics**: Leveraging data from both mental health and nutritional habits, the ML model develops predictive analytics. Evaluating patterns related to nutritional intake alongside mental well-being identifies subtle changes that may predict episodes of increased symptom intensity, relapses, or alterations in dietary habits. This improves the model's ability to predict holistic changes in a person's well-being.
3. **Early warning system**: Serving as a preventative measure, the NeuroPredict Platform identifies early indicators of impending relapse or exacerbation of symptoms, including dietary modifications and mental health issues. Changes in nutritional patterns that could affect mental health can be identified through predictive analytics related to eating habits. It is possible to identify a possible change in food habits and mental

health state by identifying deviations from baseline patterns, which enables thorough and prompt interventions.

4. **Personalized interventions**: The NeuroPredict Platform creates tailored interventions in response to early warnings regarding dietary modifications and mental health. In addition to addressing mental health issues, the method includes customized nutrition management techniques. These interventions could involve hints for changes in nutritional intake or physical activities in addition to suggestions for improving sleep hygiene and medication adherence. ML-driven insights on eating patterns and preferences help provide individualized dietary recommendations that support each person's unique mental health objectives.
5. **Real-time feedback**: Real-time feedback on food choices and mental health can be easily provided by the NeuroPredict Platform. Users get instantaneous advice and insights about their eating habits and mental health. The ML approach provides dynamic feedback on dietary decisions by continuously analysing dietary data. It takes into account things like nutritional balance, following dietary guidelines, and how eating habits affect mental health. Healthcare professionals receive a complete, real-time picture, which allows them to take immediate action in the areas of nutrition and mental health.
6. **Continuous learning**: The ML model is always learning and adapting, as it is continuously related to the data on eating habits and mental health. Over time, the accuracy of predictions and interventions is improved through the iterative learning process. The methodology guarantees a more sophisticated knowledge by taking changing dietary needs and preferences along with mental health issues into account. Through a continual learning approach, the system can improve synergistically, providing customized help for people who are managing their nutritional needs and schizophrenia.

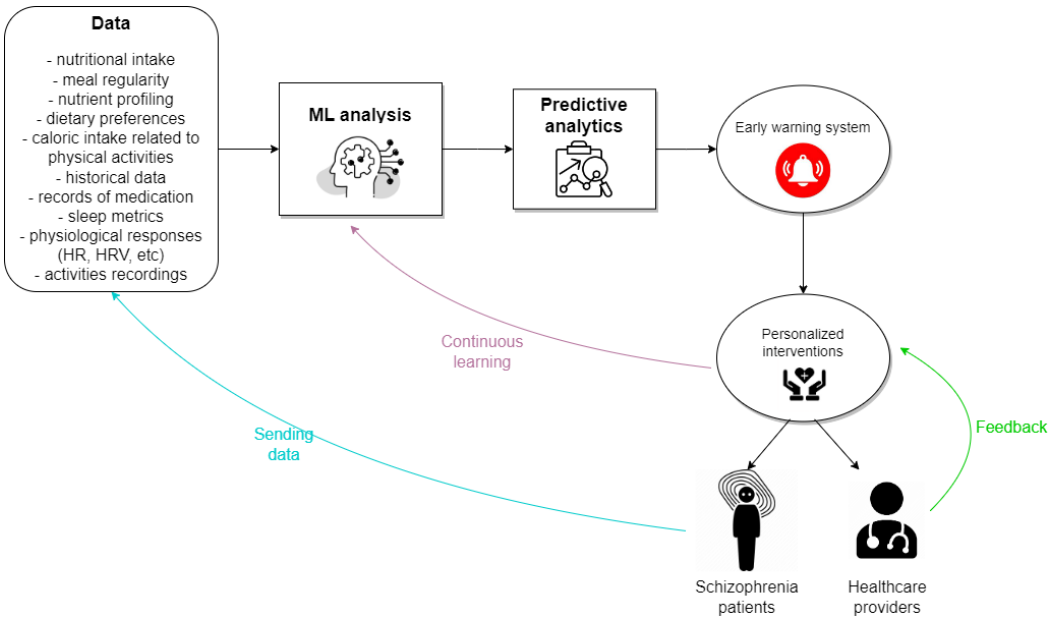

Figure 4. The use case flow for an application of personalized approach towards the patients with schizophrenia using ML.

Therefore, the integration of advanced technologies, such as RHMS, emerges as a promising avenue for personalized and proactive care. The comprehensive monitoring facilitated by RHMS allows for a nuanced understanding of various aspects influencing schizophrenia, including medication adherence, sleep patterns, physiological responses, and social interactions. The ML analysis of the medical- and physical-related data reveals intricate patterns that can serve as early indicators of relapse or symptom exacerbation, enabling timely and personalized interventions. This can be further integrated into the

RHMS in order to provide personalized dietary management and a good quality of life for patients with schizophrenia. This can underscore the potential to transform traditional paradigms of treatment.

As we move forward in the realm of mental healthcare, the integration of RHMS and ML not only provides a means for real-time monitoring but also opens avenues for tailoring interventions based on individualized patterns. The proactive nature of this approach, informed by predictive analytics, aligns with the broader goal of enhancing the quality of life for individuals with schizophrenia.

The correlation between dietary habits and schizophrenia adds a valuable layer to our understanding, signalling the need for comprehensive and holistic interventions. Future research endeavours will delve deeper into unravelling the intricate interplay between dietary choices, physiological responses, and mental health outcomes to refine our approach to schizophrenia management.

The integration of the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system is projected to produce a broad range of outcomes, considerably improving healthcare delivery and disease management. These advantages include improved patient outcomes as a consequence of increased monitoring and targeted therapies. The deployment of smart monitoring environments allows for remote monitoring, eliminating the need for frequent hospital visits and increasing efficiency for both patients and healthcare professionals. Predictive modelling and continuous monitoring provide proactive care, lowering the risk of complications and hospitalisations. Patients are now provided with real-time access to health data, nutritional insights, and tailored recommendations, allowing them to make more informed decisions and participate actively in healthcare management.

These RHMS enable patients to actively manage their medical conditions, fostering a sense of empowerment and self-efficacy. The integration of diverse technologies and data sources allows for holistic disease treatment, resulting in a thorough understanding of patients' well-being. Customized diet-related disease management solutions address patients' particular demands, taking into account age, neurological disorders, and liver health. RHMS additionally encourage connected care by allowing healthcare practitioners, patients, caregivers, and specialists to communicate and collaborate more effectively. Teleconsultations enable virtual exchanges between patients and healthcare providers, improving communication and allowing for timely treatment plan adjustments.

These RHMS' advanced analytics and AI capabilities enable data-driven decision making, supporting healthcare professionals in identifying patterns, correlations, and trends to improve disease management. Long-term data storage and analysis enable to improvement knowledge of health patterns and the efficacy of medical treatments over time. Furthermore, the data collected by these RHMS can provide useful insights into medical research, assisting in the knowledge of age-related variables, neurological disorders, and liver health. The associated research projects contribute to advances in AI, intelligent monitoring, and disease prediction.

The integration of the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system with RHMS revolutionizes the management of diet-related diseases. Ensuring data accuracy in smart monitoring environments is foundational to RHMS success. Calibration, regular maintenance, and user education are critical strategies. Integration of AI and machine learning enhances data evaluation processes, emphasising the importance of high-quality training data and continuous validation for accurate conclusions. The comprehensive monitoring capabilities of the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system contribute to the development of tailored interventions. Multidisciplinary collaboration ensures cohesive and well-coordinated strategies for managing diet-related diseases.

Strengths and Limitations of the Three Tailored Patient-Centric RHMS

The **RO-SmartAgeing system** uniquely addresses age-related factors, providing a holistic view of the long-term impact of dietary choices on ageing. The comprehensive data have the potential to assist in tailoring personalized interventions for age-specific diet-related disease management. The RO-SmartAgeing system tracks age-related factors, contributing to a holistic understanding of an individual's health. Predictive analytics anticipate challenges associated with ageing and dietary management, while secure data management practices ensure privacy. Analysing the strengths and limitations of the system provides a comprehensive understanding of its impact on personalized diet-related disease management:

- *Strengths*
- Holistic age-related monitoring: The RO-SmartAgeing system excels in providing a holistic view of the long-term impact of dietary choices on ageing. Incorporating devices like the Withings BPM Core and Glucometer CareSens enables continuous monitoring of cardiovascular health and blood glucose levels. This comprehensive dataset contributes to a nuanced understanding of age-related health dynamics;
- Tailored interventions: The continuous monitoring capabilities facilitate the tailoring of interventions for age-specific diet-related disease management. Healthcare professionals can leverage real-time data to design personalized strategies, optimising treatment efficacy;
- Secure data management: The system prioritizes secure data management, ensuring the privacy of sensitive health information. Robust data security measures contribute to the overall reliability and trustworthiness of the monitoring environment.
- Limitations
- Device integration: While the system integrates essential devices like Withings BPM Core and Glucometer CareSens, the range of monitored parameters may have room for expansion. Incorporating additional devices for a more extensive health data spectrum could enhance the system's capabilities;
- Interoperability challenges: Ensuring seamless integration with other RHMS platforms and medical devices may pose challenges. Interoperability issues can hinder the system's ability to exchange data efficiently with diverse healthcare technologies;
- User accessibility: The effectiveness of the system depends on user adherence and accessibility. Challenges may arise if users face difficulties in adopting or consistently using the monitoring devices, potentially impacting the accuracy and continuity of data.

The **NeuroPredict Platform**, incorporating advanced algorithms, enhances understanding of the interplay between brain health and dietary patterns. Devices like Moodmetric Smart Ring and MySignals EMG capture neurological signals, contributing to a holistic health assessment. Real-time data synthesis and predictive analytics anticipate challenges, providing insights for proactive neurological health and dietary management. A thorough analysis of the strengths and limitations of the system offers valuable insights into its role in personalized diet-related disease management.

- *Strengths*
- Advanced algorithms: The NeuroPredict Platform stands out for its incorporation of advanced AI algorithms, providing an enriched understanding of how neurological factors interplay with dietary habits. These algorithms cover subtle topics regarding schizophrenia management, including meal regularity, nutrient profiling, dietary preferences, and associations between calorie consumption and physical activity, going beyond simple tracking of nutritional intake;
- Real-time data synthesis: The platform facilitates real-time synthesis of health data, offering healthcare professionals swift access to the most recent information. This feature is particularly crucial in managing diet-related diseases, providing prompt insights into the impact of dietary habits on neurological health. This NeuroPredict

Platform's strength involves dynamic analysis of dietary choices, allowing for continuous monitoring of changes in dietary behaviours. This dynamic approach enables healthcare professionals to observe fluctuations, trends, or sudden deviations in an individual's dietary patterns as they occur, providing insights into potential correlations with mental health states;

- Predictive analytics for proactive management: Leveraging predictive analytics, the NeuroPredict Platform anticipates challenges related to neurological health and dietary management. By identifying patterns and trends in health data, healthcare professionals can proactively address potential issues before they escalate. Predictive analytics, thus, enable the system to detect deviations from baseline dietary patterns, signalling possible changes in mental health status, enhancing the management of both schizophrenia and dietary concerns;
- Patient engagement through direct access: The platform empowers patients by providing direct access to their health data. This feedback loop is informed by continuous analysis of dietary data using ML algorithms. Patients receive real-time advice and insights about their eating habits, enabling them to make informed decisions and adjustments to their dietary choices. This engagement fosters active participation in their own care, enhancing the collaborative efforts between healthcare professionals and patients in managing diet-related diseases.
- Limitations
- Scope of neurological monitoring: While the platform excels in capturing certain neurological signals, there may be opportunities for expansion to encompass a broader spectrum of neurological parameters. Including additional monitoring capabilities could provide a more comprehensive neurological health assessment. Comprehensive monitoring of brain activity, including cognitive functions related to dietary choices, is a complex endeavour. The platform's current capabilities may not provide a granular understanding of how neurological factors intricately influence dietary preferences, decision-making processes, and the cognitive aspects of nutritional intake. Moreover, understanding how individuals cognitively perceive and react to dietary suggestions or information about their eating patterns may be outside the current reach of neurological monitoring, even though physiological markers and stress responses offer insightful information;
- User education and adoption: The effectiveness of the NeuroPredict Platform relies on user understanding and consistent usage of the monitoring devices. Enhancing user education and adopting user-centric design features can address potential challenges associated with user adherence. In addition, the ML algorithms driving the NeuroPredict Platform are sophisticated and designed to autonomously analyse extensive sets of data. The complexity of these algorithms may pose challenges in terms of user comprehension, who may find it difficult to completely understand the subtleties of how ML algorithms work in the context of managing eating habits, especially when it comes to schizophrenia patients;
- Dependency on predictive models: Like any system employing predictive analytics, the accuracy of predictions depends on the continuous refinement and validation of the underlying models. Inaccuracies in predictive models may impact the platform's ability to foresee and address neurological health challenges effectively. It could be also difficult for models to generalize predictions to people with distinct dietary habits or cultural differences. For the platform to be effective, bias must be reduced, and generalisation capabilities must be improved to properly consider different dietary habits. It is also important to ensure the robustness of these models against external influences to maintain their reliability. The impact of external factors, such as changes in lifestyle, environmental influences, or socioeconomic conditions, on dietary habits, may present challenges for the reliance on predictive models, potentially introducing variability in individuals' nutritional choices.

Specialising in liver health monitoring, the **HepatoConect system** integrates devices like the Withings Body+ and Withings Sleep Analyzer. This system ensures real-time monitoring of liver function and offers personalized insights for tailored dietary recommendations, as dietary interventions aimed at improving overweight (including sarcopenic obesity) and metabolic abnormalities, as well as combating malnutrition and sarcopenia in LC should become part of routine care in hepatology. The focus on secure data management safeguards sensitive information, contributing to a comprehensive and secure monitoring environment. A comprehensive analysis of the system's strengths and considerations sheds light on its role in personalized disease management.

- *Strengths*
- Tailored for liver disease monitoring: the HepatoConect system excels in monitoring liver health, offering real-time insights into vital health data related to liver function but also provides remote monitoring solutions for potential comorbidities;
- Personalized dietary recommendations: Leveraging real-time monitoring, the system provides personalized insights for tailored dietary recommendations specific to liver health. This targeted approach ensures that interventions are customized to address the unique requirements of individuals managing diet-related diseases;
- An original multifaceted approach: provided by integrating comprehensive educational resources, solutions for remote evaluation of nutritional status, and individualized telemonitoring interventions through innovative technology.
- Limitations
- Scope beyond liver health and virtual frailty assessment: While the system excels in monitoring liver health, exploring opportunities to expand its scope to encompass a broader range of health parameters may enhance its overall utility. Integrating additional monitoring capabilities could provide a more comprehensive health assessment;
- User engagement and commitment: The effectiveness of the HepatoConect system is contingent on user engagement and consistent commitment to monitoring protocols. Implementing user-friendly features and educational initiatives can address potential challenges associated with user adoption and adherence;
- Interoperability with comprehensive health systems: Ensuring seamless integration and interoperability with broader comprehensive health systems can enhance the system's contribution to multidisciplinary collaboration. This interoperability facilitates cohesive strategies for managing diet-related diseases across various healthcare specialities;
- Integration of AI and predictive analytics: The current HepatoConect system does not have capabilities of cross-sectional imaging data integration and interpretation through advanced analytics, and it is an important feature to consider for nutritional evaluation and screening in LC patients. A current limitation but a future capability of the system, as it is still under development and continuous improvement, integration of cutting-edge technologies is the ultimate goal of the HepatoConect system.

Future Directions

Future research may explore the optimisation of age-related monitoring in the RO-SmartAgeing system. Combining cutting-edge technologies with current ones, including AI-powered predictive modelling and epigenetic markers, might provide insights into the complex relationship between ageing, dietary habits, and health outcomes. The system's reliability and applicability might be expanded by the development of noninvasive age evaluation methods, such as advanced imaging or innovative sensors, which could also establish new benchmarks for efficiency in age-related health monitoring.

With its emphasis on dietary habits and neurological health, the NeuroPredict Platform offers improved insights for comprehensive healthcare. In order to collect thorough neurological data, future research may address the merging of wearables with more advanced neuroinformatics technologies. Advanced machine learning algorithms might identify multiple connections between brain data, dietary habits, and general health outcomes.

The in-depth knowledge of the HepatoConect system to monitor the condition of the liver creates opportunities for personalized healthcare. For a more thorough evaluation of liver function, future research might incorporate biomarkers or advanced imaging tools. The incorporation of real-time liver data might provide the basis for the creation of tailored pharmaceutical therapies, harnessing advances in personalized drug delivery and pharmacogenomics.

4. Conclusions

In summary, an important breakthrough in the management of diet-related disorders has been brought about by the integration of the RO-SmartAgeing system, NeuroPredict Platform, and HepatoConect system with RHMS. The initiative leverages cutting-edge technologies and medical knowledge to thoroughly manage multiple elements of health monitoring, data precision, and tailored approaches. Through the easy integration of these systems into healthcare, a multifaceted pathway is implemented to address the intricacies of diet-related diseases.

The combined capabilities of the HepatoConect system, NeuroPredict Platform, and RO-SmartAgeing system enable the creation of specific approaches for the successful management of diet-related disorders. Solid and tightly integrated methods are promoted through multidisciplinary collaboration, guaranteeing an exhaustive and patient-centric approach to healthcare, with a special emphasis on the management of diet-related diseases. As technology continues to advance, future research endeavours may focus on improving age-related monitoring, investigating emerging methods for noninvasive evaluations, incorporating advanced neuroinformatics tools, and exploring tailored medication therapy for liver health. This proactive outlook highlights the continuous improvement of assessment techniques linked to RHMS potential, driving progress in the field of diet-related disease management.

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