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TELEMONITORING IN CHRONIC DISEASES: AVAILABLE SOLUTIONS AND EFFECTIVENESS RESEARCH REVIEW

Introduction

Chronic diseases are long-lasting and often accompany patients for the rest of their lives even if they are not the cause of death. Their prolonged course results in the need for constant monitoring and support of the health care system. Consequently, this causes a significant burden to the system due to recurring appointments, consultations and – in the case of exacerbation – emergency assistance or even hospitalizations. Chronic diseases are currently a major burden to health care systems in developed countries. Thus, the demands from health care systems that should cope with the care over patients with chronic diseases include the requirement of the continuity of care as well as the shared care or patient's self-empowerment. All this should be accompanied by adequate care quality, patient's security and – if possible – limited costs of treatment.

When looking at the evolution of telemedicine and e-health systems, one can easily realize that the development of such technologies resulted from the search for strategies and tools that would effectively meet at least some of the above listed requirements. Early telemedicine systems were developed thanks to the efforts of a small circle of enthusiasts who wanted to show the world the possibilities of ICT technologies in medicine. However, the opportunities to apply them were soon assessed from the point of view of their role in the improvement of the access to health services or their distribution in particular groups.

The application of ICT systems to support patients with chronic diseases became more realistic with the development of web and subsequently mobile technologies. A universal access to the Internet does not only mean a revolution as regards the use of information and services but also a democratization of the access to these resources. The technology is a chance to provide a continuous and comprehensive care to patients with chronic diseases, who constitute a significant and - due to demographic trends –an increasing part of the population.

The process of monitoring chronic disease patients, no matter whether technological tools are used or not, is a key element of medical care. This fact is reflected by international guidelines whose aim is to help make rational decisions by doctors and other healthcare staff. The application of e-health systems to monitor the course of chronic diseases has become an crucial element of care in several healthcare systems since the time when numerous solutions appeared to support patients in registration procedures the transfer of self-examination results and the results from the devices that repeatedly measure selected physiological parameters.

1. Telemonitoring of chronic diseases

Telemonitoring means the use of audio, video or other ICTs in remote monitoring of patient's health. The architecture of telemedicine systems, including telemonitoring systems that are used in the care of patients with chronic diseases, usually consists of three tiers[1]. Tier 1 consists of devices with sensors which record physiological parameters, e.g. oxygen saturation of blood or the ECG signal. The signal from these devices is transmitted through Local Area Network (LAN) or Wireless Body Area Network (WBAN) to Tier 2, which usually is a personal gateway such as a mobile phone or notebook. The data from Tier 2 are sent through Wide Area Network (WAN), e.g. the Internet, mobile phone network or landline telephony, to the IT system of the service provider, i.e. Tier 3[2].

The solutions applied to telemonitor chronic diseases are usually based on devices with sensors that register indices that are crucial for particular diseases, e.g. glycemic index or oxygen saturation of arterial blood in advanced obstructive pulmonary disease (COPD). Some of these devices operate autonomously without the patient's cooperation while some require switching on and making a measurement. One should keep in mind that the sensors can also be installed in in-house environments in order to monitor phenomena that are crucial as regards the health of patients, such as activities of daily living or their mobility[3]. One of the available classifications of activities and phenomena that can be monitored in medical systems

[1] O.S. Albahri, A.S. Albahri, K.I. Mohammed, A.A. Zaidan et al., *Systematic review of real-time remote health monitoring system in triage and priority-based sensor technology: Taxonomy, open challenges, motivation and recommendations*, Journal of Medical Systems, 2018, No. 42(5), p. 80.
[2] Ibidem.
[3] L. Liu, E. Stroulia, I. Nikolaidis, A. Miguel-Cruz et al., *Smart homes and home health monitoring technologies for older adults: A systematic review*, International Journal of Medical Informatics, 2016, No. 91, pp. 44-59.

distinguishes: physiological activities such as heart rate, brain and muscle activities; mental activities such as memory, understanding, judgement; mobility activities such as walking, running, getting up, sitting, lying; everyday activities such as eating, getting dressed, personal hygiene activities; and instrumental activities of daily living such as preparing a meal, cleaning, taking medicine[4].

The initial telemonitoring systems of chronic diseases applied landline telephones[5]. With the development of wireless technologies, wireless telephony was also commonly used in medical systems. The implementation of mobile wireless solutions gave start to a field of e-health which is referred to as m-health. One of the first definitions of m-health was suggested by Istepanian and Lacal[6]. According to them, m-health is the use of telecommunication and multimedia technologies in mobile and wireless systems of healthcare[7].

Currently, telemonitoring systems integrate ubiquitous computing and communication technologies. The systems include three components: sensing, communication and the processing system[8]. They are not simple applications that facilitate the transfer of data from sensing devices to service providers but complex systems that facilitate the participation and interaction of users, patients, their (formal and informal) caretakers and the representatives of several professions that are employed by healthcare service providers such as doctors of various specializations, nurses or physiotherapists.

2. Wireless sensors and wearables

Wearable technology is an important element of telemonitoring systems that are used in healthcare. Wearables include electronic devices with microprocessors that have the option of wireless communication and can be worn as independent devices or parts of clothing; they can be implanted or even have a form of a tattoo. Wearables also include swallowable pills that are used in the diagnostics of gastrointestinal diseases. Wearable technologies are defined as smart, low-cost sensor devices placed on or inside the body and designed to provide services which

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[4] H. Mshali, T. Lemlouma, M. Moloney, D. Magoni, *A survey on health monitoring systems for health smart* homes, International Journal of Industrial Ergonomics, 2018, No. 66, pp. 26-56.
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[7] Ibidem.
[8] H. Mshali, T. Lemlouma, M. Moloney, D. Magoni, *A survey…,* op. cit., pp. 26-56.

involve the storage of a vast amount of medical data in order to support the users[9]. The development of this technology gained in momentum with the expansion of wireless networks. One should remember that wearables are used not only in healthcare but also in many other areas such as recreation, entertainment or communication.

M.Alrige and S.Chatterjee proposed a taxonomy of wearable technologies used in healthcare in terms of three dimensions: application, functionality and form[10]. The area of application includes monitoring, supporting technologies, disease prevention and communication. The area of functionality includes two options: single or numerous functions depending on the number of parameters that are measured by the wearables. The area of form includes four elements: accessories, clothing, implantable and mobile devices. The accessories are used to support the lifestyle. This concerns smartwatches, smart glasses or shoes. Mobile devices include smartphones and video cameras with microphones. Smart clothing or the so-called e-fabrics are used to collect physiological data but they also store data concerning, for example, the user's mobility. The design of implantable devices make it possible to place them inside human body; sensors monitoring glucose levels to treat diabetes are a good example here[11].

3. Usefulness and effectiveness of telemonitoring

There are numerous articles concerning the effectiveness of telemonitoring systems in the treatment of chronic diseases. The article discusses the results of the latest systematic reviews and meta-analyses published in 2018-2019 which assessed the effectiveness of telemonitoring in the cases of selected, typical chronic diseases. The assumption was that the comparisons of telemonitoring effectiveness with "usual healthcare" that were taken into consideration in previous evidence syntheses were also subject to systematic reviews which have been published lately. It should be emphasized that despite a significant interest in the application of e-health systems in particular areas of care over patients with chronic diseases, the benefits of the application of telemonitoring in many cases were not as obvious as expected.

[9] M. Chan, D. Estève, J.-Y. Fourniols, C. Escriba et al., *Smart wearable systems: Current status and future challenges*, Artificial Intelligence in Medicine, 2012, No. 56, pp. 137–156; M. Alrige, S. Chatterjee, *Toward a taxonomy of wearable technologies in healthcare,* [in:] B. Donnellan, M. Helfert, J. Kenneally, D. VanderMeer, M. Rothenberger, R. Winter, (ed.), *New Horizons in Design Science: Broadening the Research Agenda. DESRIST 2015. Lecture Notes in Computer Science*, No. 9073. Springer, Cham, 2015, pp. 496-504.
[10] Ibidem.
[11] K. Scholten, E. Meng, *A review of implantable biosensors for closed-loop glucose control and other drug delivery applications*, International Journal of Pharmaceutics, 2018, No. 544(2), pp. 319-334.

The telemonitoring effectiveness is evaluated in relation to numerous indices that are clinical or non-clinical. In 2018, a review was published of the criteria that were applied until 1990 to evaluate noninvasive telemonitoring systems for patients with heart failure[12]. The authors of the review identified as many as 52 criteria that appeared in 128 studies. They classified 6 main dimensions: clinical, economic, user perspective, educational, organizational and technical. Clinical and economic criteria were assessed in over 70% of studies, whereas the remaining ones – apart from the user perspective criteria – were studied in less than 15%. The discussion below of telemonitoring effectiveness in particular chronic diseases concentrates mainly on clinical indices.

It should also be emphasized that the presentation below of the latest results covers only the selected diseases that usually do not only have a significant social significance but also have well-defined parameters that require long-term control and monitoring. The presentation does not include studies where the use of e-health systems consisted in therapeutic activities such as psychotherapy of physiotherapy but in the transmission of physiological parameters or patients' self-observations.

3.1. Heart failure

The evaluation of the remote monitoring of patients with heart failure was subject to numerous systematic reviews and meta-analyses that were published in the last decade. Only in 2018 there were a few studies that constituted an evidence synthesis of this period.

The comparison of healthcare based on telemonitoring with a usual care was the subject of a systematic review and meta-analysis conducted by Yuna et al.[13]. The telemonitoring effectiveness was assessed by such criteria as mortality, hospitalizations, emergency assistance and indices reported by patients. A total of 37 randomized clinical trials with a control group (RCTCT) were subject to analysis. However, the number of trials that were taken into consideration in the assessment of particular effectiveness indices varied (from 24 trials that considered all-cause mortality to 5 trials where heart failure related - mortality was assessed). According to meta-analysis, telemonitoring resulted in a decrease in mortality caused by all causes and heart failure. Telemonitoring was substantially beneficial when at least 3 parameters

[12] T. Farnia, M.C. Jaulent, O. Steichen, *Evaluation criteria of noninvasive telemonitoring for patients with heart failure: systematic review*, Journal of Medical Internet Research, 2018, No. 20(1), e16.
[13] J.E. Yun, J.E. Park, H.Y. Park, H.Y. Leeet al., *Comparative Effectiveness of Telemonitoring Versus Usual Care for Heart Failure: A Systematic Review and Meta-analysis*, Journal of Cardiac Failure, 2018, No. 24(1), pp. 19-28.

were transferred or when the transmission was conducted on a daily basis. The decrease in mortality was also noticed in the case of trials when the monitoring covered subjective symptoms reported by patients, pharmacotherapy adherence and the changes in prescribed treatment.

Pekmezaris et al. conducted a systematic review with a RCTCT meta-analysis in order to test home telemonitoring effectiveness in patients with heart failure for reducing mortality and hospital use[14]. Finally 26 trials were taken into consideration. Home telemonitoring decreased all-cause mortality and heart failure related mortality at 180 days but not at 360 days. The authors of the review did not see a significant impact on all cause hospitalization at 90 or 180 days or on heart failure-related hospitalization at 180 days. However, telemonitoring significantly increased the odds of emergency department visits at 180 days after the intervention started[15].

Tse et al. conducted a RCTCT meta-analysis and research to assess the effectiveness of telemonitoring and hemodynamic monitoring to reduce hospitalization rates of heart failure patients[16]. The telemonitoring systems that were applied in the studies under investigation registered– apart from the subjective symptoms given by patients and medical adherence – blood pressure, heart rate, body mass and diuresis in various configurations. The remote hemodynamic monitoring applied implantable sensor devices that enabled the measurement of pulmonary artery pressure in the right or left atrium[17]. The search for the new forms of hemodynamic monitoring results from the delay between the cardiovascular fluid overload and changes of non-invasive indices such as subjective symptoms or body mass. The most common monitors include: CardioMEMS HF System (Abbott, Sylmar, California, USA), Chronicle (Medtronic, Inc., Minneapolis, Minnesota, USA) and HeartPOD (Abbott, Sylmar, California, USA). Tse et al. analyzed 6 cohort and 55 RCTCT studies of 4831 patients where wireless hemodynamic monitoring was applied. The outcome was more optimistic than in the Pekemezaris et al. research[18] as the decrease of the odds of hospitalization was found in the

[14] R. Pekmezaris, L. Tortez, M. Williams, V. Patel et al., *Home Telemonitoring In Heart Failure: A Systematic Review And Meta-Analysis*, Health Affairs, 2018, No. 37(12), pp. 1983-1989.
[15] Ibidem.
[16] G. Tse, C. Chan, M. Gong, L. Meng et al., *Telemonitoring and hemodynamic monitoring to reduce hospitalization rates in heart failure: a systematic review and meta-analysis of randomized controlled trials and real-world studies*, Journal of Geriatric Cardiology, 2018, 1 No. 5(4), p. 298.
[17] W.T. Abraham, L. Perl, *Implantable hemodynamic patient monitoring for heart failure*, Journal of the American College of Cardiology, 2017, No. 70(3), pp. 389-398.
[18] R. Pekmezaris, L. Tortez, M. Williams, V. Patel et al., *Home Telemonitoring…,* op. cit., pp. 1983-1989.

case of both types of systems in the short- (up to 6 months) and long-term (at least 12 months) perspective.

3.2. Hypertension

The meta-analysis that was published by Choi et al. in 2019 showed that although telemonitoring resulted in a statistically substantial reduction of systolic blood pressure, the difference in comparison to usual care was isignificant as regards cardiovascular complications[19]. In the case of diastolic blood pressure, the difference was even smaller and also negligible as regards complications. It should be emphasized that the analysis covered only urban patients. The effects presented above are not very optimistic but it should be pointed out that previous reviews seem to indicate a more significant reduction of blood pressure after the application of telemonitoring[20].

3.3. Diabetes

In 2018 a systematic review was published together with a meta-analysis of research which compared the effectiveness of telemonitoring versus usual care of type 2 diabetes [21]. The review covered 38 examinations in which 6855 patients were involved. It turned out that telemonitoring-based care versus usual care lead to a significant reduction of glycated hemoglobin (HBA1c). This effect was noticed when systems were applied that were based on the transfer of physiological data from the Internet-based devices both through verbal messages sent ad hoc or on daily basis and in the case of a general advisory service. Moreover, a beneficial outcome was obtained in the case of systems that included monitoring recommendation adherence, the provision of advisory services, education and alerts. Meta-analysis confirmed a statistically significant reduction in systolic blood pressure and BMI. However, the change in the value of these indices was insignificant.

[19] W.S. Choi, J.H. Choi, J. Oh, I.S. Shin et al., *Effects of Remote Monitoring of Blood Pressure in Management of Urban Hypertensive Patients: A Systematic Review and Meta-Analysis*, Telemedicine and e-Health, 2019, [forthcoming, available online]
[20] R. Purcell, S. McInnes, E.J. Halcomb, *Telemonitoring can assist in managing cardiovascular disease in primary care: a systematic review of systematic reviews*, BMC family practice, 2014, No. 15(1), p. 43.
[21] Y. Kim, J.E. Park, B.W. Lee, C.H. Jung et al. *Comparative effectiveness of telemonitoring versus usual care for type 2 diabetes: A systematic review and meta-analysis*, Journal of Telemedicine and Telecare, 2018 forthcoming].

In 2018, a systematic review was published of digital interventions for supporting patients with poorly controlled type 2 diabetes[22]. It showed that also in the case of such patients the use of web-based interventions resulted in a significant reduction of HbA1c level.

3.4. Bronchial asthma (BA)

In 2017 a meta-review was published that focused on the effectiveness assessment of tele-medical technologies for supporting patients with chronic diseases which also covered patients with bronchial asthma[23]. The outcome of the study was not obvious in the case of bronchial asthma but none of the reviews in the meta-review indicated poorer outcome after the application of telemonitoring . However, a more significant improvement was noticed after the application of more intensive and complex interventions that involved the tools of telemedicine.

The objective of the systematic review that was published this year was to assess the tele-monitoring effectiveness in children and adolescence with bronchial asthma[24]. The analysis covered 8 RCTCTs and it showed that the symptom control rate and the number of disease exacerbations did not differ significantly with regard to the usual care and the care with telemonitoring. The authors of the review concluded that telemonitoring resulted in the improvement in medication adherence.

However, the review of R.Jeminiwa et al. which was also published this year indicated that the most significant improvement in adherence to therapeutic recommendations was achieved after the application of m-health interventions with the elements of telemonitoring[25].

3.5. Chronic obstructive pulmonary disease (COPD)

In 2018, A.R.Sul et al. published a systematic review with meta-analysis[26]. Its objective was to determine telemonitoring effectiveness versus usual care in COPD. The study involved

[22] M.M. Kebede, H. Zeeb, M. Peters, T.L. Heise et al. *Effectiveness of digital interventions for improving glycemic control in persons with poorly controlled type 2 diabetes: a systematic review, meta-analysis, and meta-regression analysis*, Diabetes Technology & Therapeutics, 2018, No 20(11), pp. 767-782.

[23] P. Hanlon, L. Daines, C. Campbell, B. McKinstry et al., *Telehealth interventions to support self-management of long-term conditions: a systematic metareview of diabetes, heart failure, asthma, chronic obstructive pulmonary disease, and cancer*, Journal of Medical Internet Research, 2017, No 19(5), e172.

[24] Y. Jung, J. Kim, D.A. Park, *Effectiveness of Telemonitoring Intervention in Children and Adolescents with Asthma: A Systematic Review and Meta-Analysis*, Journal of Korean Academy of Nursing, 2018, No 48(4), pp. 389-406.

[25] R. Jeminiwa, L. Hohmann, J. Qian, K. Garza et al, *Impact of eHealth on medication adherence among patients with asthma: A systematic review and meta-analysis*, Respiratory Medicine, 2019, No 149, pp. 59-68.

[26] A.R. Sul, D.H. Lyu, D.A. Park, *Effectiveness of telemonitoring versus usual care for chronic obstructive pulmonary disease: A systematic review and meta-analysis*, „Journal of Telemedicine and Telecare, 2018 [forthcoming].

28 RCTCTs. The conclusion of the analysis is that there are no differences between the two forms of care as regards exacerbation of the disease (6 trials) and mortality (7 trials). The analysis in subgroups indicated that telemonitoring resulted in the frequency reduction of exacerbation when interventions lasted over 6 months or in the cases when the monitoring concerned lung function. No differences were observed as regards the variables reported by patients (such as life quality or dyspnea) or the utilization of healthcare resources (duration and number of hospitalizations and emergency department visits).

Y. Hong, S.H. Lee conducted a review and meta-analysis of articles on the impact of telemonitoring on COPD effectiveness[27]. The analysis covered 27 articles that were published until April 2017. It indicates that telemonitoring resulted in a significant reduction of the number of emergency department visits and hospitalizations) by at least 10%. The analysis in subgroups showed that telemonitoring was more effective as regards emergency department visits and.

Conclusions

Long-term control of selected physiological parameters and the results of self-control or patient-based measurements is the basis for effective treatment in numerous chronic diseases. Such diseases have frequently a significant impact on the state of health of society as well as the economic burden to healthcare system. The implementation of e-health systems that make it possible to monitor remotely patients' health condition provides the opportunity to improve healthcare and cooperation on the part of patients as well as – in many cases – the effectiveness of treatment and the reduction in the use of healthcare resources. The outcome of the comparison between the usual and telemonitoring–based care is not always clear. There are also differences in particular chronic diseases as regards the ways how effectiveness indices can be improved.

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Abstract

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