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ACTUALITY OF MODERN REMOTE REHABILITATION (literature review)

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Remote rehabilitation is an innovative approach that allows patients to receive medical support and rehabilitation services in a convenient and safe way in their own home or remotely from a medical facility. Remote rehabilitation can be used for a wide range of medical conditions and problems, including physical therapy, rehabilitation after injuries or surgeries, pain management, rehabilitation after stroke, Parkinson's disease and other neurological diseases, pulmonary rehabilitation for patients with chronic obstructive pulmonary disease, as well as psychological support and counseling. This approach may include the use of video communication, monitoring of physiological parameters, mobile applications, and sensors to measure progress and monitor the patient. Remote rehabilitation is especially useful in situations where it is difficult or impossible for patients to physically visit a medical facility, for example, due to physical activity limitations, remote geographical locations, or epidemiological circumstances. Remote rehabilitation has both positive and negative aspects. Positive aspects: accessibility – allows patients to get the help they need regardless of location; convenience – to receive rehabilitation services at a time and place convenient for them; cost – can be more cost-effective, as it reduces travel and accommodation costs for patients. Negative aspects: lack of direct contact; limited capabilities – some types of therapy that require guidance or correction from a specialist may be less effective in a remote format; technological problems. It is important to consider these positive and negative aspects of remote rehabilitation when deciding whether to use it. The specific circumstances and needs of the patient may affect the effectiveness of this approach to rehabilitation. Remote rehabilitation is a promising area in medicine, as it allows for increased accessibility and convenience of rehabilitation services for patients. It can also help reduce the burden on healthcare facilities and reduce the cost of organizing rehabilitation programs.

Keywords: *rehabilitation technologies, rehabilitation services, mobile technologies, positive and negative aspects.*

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Physical rehabilitation is a process that uses patient assessment and individualized treatment programs, which, unfortunately, often remain limited by the resources of medical centers. Recently, we have seen the rapid development of a modern trend in the healthcare sector – telemedicine and remote rehabilitation.

Modern mobile technologies are becoming an important, potential and effective solution for objective assessment and monitoring of patients inside and/or outside the clinical environment. The information obtained with the help of this technology provides a more detailed assessment of the patient's well-being and helps determine the optimal rehabilitation therapy [1]. The advantage of these devices in terms of portability, low cost, and unobtrusive sensors makes this technology highly effective for tracking movements to improve care for patients with neurological or musculoskeletal diseases. In addition, these sensors allow for quantitative assessment of motor behavior, which is useful for compensatory mechanisms of musculoskeletal rehabilitation, remote monitoring and telerehabilitation using robotics [2–4].

The relevance and advantages of this area also lie in the fact that remote rehabilitation overcomes geographical barriers and provides access to rehabilitation services for people who may have limited mobility or live in remote areas. This ensures that people who have had a stroke can receive timely and necessary assistance regardless of their location [5]. Allows for continuous monitoring and follow-up, ensuring that stroke survivors receive ongoing care even after discharge from the hospital. Healthcare professionals can remotely assess patient’s progress and make adjustments to their treatment plans, contributing to better outcomes [6].

From an economic perspective, remote rehabilitation has the potential to reduce healthcare costs associated with in-person visits, such as transportation costs and prolonged hospital stays. It also optimizes the use of healthcare resources and provides a more cost-effective approach to providing rehabilitation services [7]. It can provide personalized interventions tailored to the unique needs of each stroke survivor. Thanks to telemedicine technologies, healthcare professionals can remotely monitor patients, provide recommendations and prescribe exercises and therapies appropriate to their condition, increasing the effectiveness of the rehabilitation process [5].

Remote rehabilitation offers convenience and flexibility, as it allows stroke survivors to receive care from the comfort of their own homes. This reduces the burden of travel and increases patient engagement, leading to greater compliance with the rehabilitation program [6]. Remote rehabilitation combines remote data collection and processing, personalized user-centered technologies, and artificial intelligence. Data from smartphone applications and the ever-growing number of mobile devices with environmental sensors can be processed by artificial intelligence

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and help adjust the rehabilitation program. In general, it provides valuable support after discharge from the hospital. It helps to eliminate functional limitations, provides self-control training, and helps to return to daily activities, contributing to better long-term recovery [5].

Telerehabilitation is a fairly young area of healthcare that is actively developing and being researched. Currently, there are four stages in the development of telemedicine:

I. Early development (late 20^{th} century): telerehabilitation started as an experimental approach, primarily focusing on video consultation between healthcare professionals and patients; initial efforts were focused on assessing the feasibility and effectiveness of remote rehabilitation interventions, especially in rural or underserved areas.

II. Technological advances (2000s): with the development of technologies such as high-speed Internet, improved video conferencing capabilities, and wearable devices, telerehabilitation expanded its scope; the development of user-friendly software, mobile applications, and specialized devices facilitated the remote delivery of rehabilitation services; researchers and healthcare professionals began to explore the use of telerehabilitation in various rehabilitation fields, including physiotherapy, occupational therapy, and speech therapy.

III. Research and Evidence (2010s): the 2010s saw a surge in research and evidence supporting the effectiveness of telerehabilitation in various patient populations; studies highlighted the positive outcomes, patient satisfaction, and cost-effectiveness of telerehabilitation compared to traditional face-to-face rehabilitation; professional associations and healthcare organizations began to develop recommendations and best practices for implementing telerehabilitation.

IV. Expanded applications and integration (present): telerehabilitation has gone beyond video consultations to include features such as remote monitoring, virtual reality, gamification, and wearable sensor technologies; with integration, it has become an integral part of healthcare systems of electronic health records and interoperability between telemedicine platforms and hospital systems; the COVID-19 pandemic has further accelerated the introduction and adoption of telerehabilitation as a mainstream way of delivering rehabilitation services [1; 3; 4; 7].

Telemedicine uses modern technological tools that provide new opportunities for both patients and medical staff. The tools and methods are constantly being improved and their capabilities are expanding, but at the moment we can highlight the main ones.

1. Teleconsultation. Virtual consultations between healthcare professionals and patients to assess, guide and monitor rehabilitation progress.

2. Telerehabilitation. Remote delivery of rehabilitation services, including exercises, therapy sessions and assessments, via video conferencing or telecommunication technologies.

3. Mobile applications. Mobile programs that offer rehabilitation exercises, progress tracking, and educational resources to support remote rehabilitation.

4. Wearable technologies such as sensors or smartwatches that track movement, collect data, and provide real-time feedback for remote rehabilitation.

5. Virtual reality (VR). Immersive virtual environments or simulations that are used for rehabilitation exercises, providing a controlled and immersive experience.

6. Gamification. The incorporation of game elements or mechanisms into rehabilitation programs to increase motivation, engagement, and adherence to exercise.

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7. Robotics. Remote-controlled or programmable robotic devices used to assist in rehabilitation exercise or therapy.

8. Sensor systems. The use of sensors to capture motor data and provide feedback during rehabilitation exercises, enabling remote monitoring and analysis [8–10].

Like any new trend in healthcare, TV rehabilitation has advantages and disadvantages compared to classical physical rehabilitation. We can highlight and adjust the main points:

advantages of remote rehabilitation:

- accessibility: remote rehabilitation allows patients to access rehabilitation services from the comfort of their homes, eliminating the need for travel and reducing barriers to access;

- convenience: patients can schedule rehabilitation sessions at a time that is convenient for them, which provides flexibility in their rehabilitation path;

- cost-effectiveness: remote rehabilitation has the potential to reduce costs associated with transportation and accommodation, especially for patients living in remote areas or with limited mobility;

- continuity of care: remote rehabilitation can provide consistent and uninterrupted care, as patients can receive regular sessions without interruptions due to factors such as weather or transportation issues;

- individualized approach: remote rehabilitation can use technology to provide personalized exercises, monitoring and feedback, tailoring the program to individual needs [3; 11; 12];

disadvantages of remote rehabilitation:

- technological barriers: some patients may face challenges in using the necessary technology, such as smartphones or computers, that are required for distance rehabilitation;

- lack of physical contact: remote rehabilitation may lack the physical touch and hands-on guidance that can be provided during in-person sessions, which can be crucial for certain aspects of rehabilitation;

- limited access to equipment: certain specialized equipment used in traditional rehabilitation settings may not be available or easily replicated for use in distance rehabilitation;

- potential communication challenges: remote rehabilitation depends on effective communication between patients and healthcare providers. technical difficulties or limitations of communication technologies may prevent clear understanding or timely feedback;

- adaptation constraints: some patients may require immediate intervention or adjustments to treatment plans based on real-time assessments, which may be more difficult to achieve in a remote location [1; 7; 11; 12].

Telemedicine, which is constantly evolving, uses new technological capabilities, combines them with modern physical rehabilitation techniques, and creates more comprehensive and individualized rehabilitation programs. Developments and research are ongoing, and the results emphasize the relevance, effectiveness, and prospects of remote rehabilitation.

Telemedicine combines the use of sensors, mobile applications, social networks, and location tracking technologies to obtain data related to health, diagnosis, prevention, and treatment of diseases. Data from smartphone applications and the ever-growing number of mobile devices with environmental sensors can be processed using artificial intelligence to help make medical decisions. An integrated approach makes it theoretically possible to monitor and intervene anywhere and anytime for acute and chronic

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diseases. The benefits of telemedicine as a form of care have become incredibly evident during the COVID-19 pandemic. Telemedicine is now an integral part of healthcare in the United States, Canada, Australia, and other developed countries. It seems that telemedicine and digital technologies have ushered in a new era of cheaper, patient-centered healthcare [12; 13].

Digital technologies in stroke rehabilitation

Stroke is one of the leading causes of disability among adults worldwide [14]. In addition, many survivors of acute cerebrovascular accident (ACVA) suffer from hemiplegia, which makes walking difficult or even impossible. Thus, the rehabilitation of post-stroke patients is aimed at restoring the functions of the musculoskeletal and nervous systems [15]. Dosed physical activity during rehabilitation has been repeatedly proven to be effective in improving muscle activity and neuromuscular control [16]. Electromyography in combination with controlled neuromuscular electrical stimulation (NMES) has shown significant benefits in restoring motor function of the upper extremities in clinical trials with stroke patients [17]. Monte-Silva et al. work in this area and offer a systematic review and meta-analysis of the effect of EMG-NMES on upper limb recovery after stroke. Another significant contribution was made by Hameed et al. [18; 19]. The authors highlight robotic devices as valuable tools that help patients in their daily activities and restore hand function through rehabilitation programs. In particular, they emphasize the potential of using SEMGs to control hand-held robotic devices, including gloves and exoskeletons, for rehabilitation activities and in everyday life.

For example, the RoboTeleRehab home robotic upper limb telerehabilitation system aims to create a new home telerehabilitation system, supplemented by a robotic and VR module, consisting of: (A) a patient's home telerehabilitation system and (B) a physician's telemonitoring system [14; 18; 20].

The system of remote rehabilitation of a patient at home consists of a commercially available cobot with two force sensors (six-axis force sensors SRI M3715C and SRI M3713C) and a special steering wheel. The cobot consists of one robot arm, one robot controller, a touch panel, and a pre-installed program called "PolyScope". The cobot arm is a kinematic equipment that can meet all the mobility criteria for human arm rehabilitation [16; 19; 21]. With the help of built-in functions, it is possible to obtain data on the speed and location of the joints of the cobot arm in real time [22].

Several studies have compared the outcomes of a center-based rehabilitation (CBCR) program with a home-based rehabilitation (HBCR) program, including improvements in cardiorespiratory fitness, quality of life, risk factor management, and mortality. HBCR participants, for example, showed an increase in 6-minute distance (462 m 74 cm vs. 421 m 90 cm, p=0.03), higher tolerance and increased physical fitness compared to CBCR participants [21; 23; 24].

Hospital rehabilitation after stroke can be limited by staffing ratios and length of stay, which can impede recovery. Thus, a home-based gamified rehabilitation system (i.e., IntelliRehab) was tested for its ability to increase cerebral blood flow (CBF) and the secondary effects of changes on upper limb motor function and functional outcomes. A pilot before-after group study was conducted to measure the impact of 3 months of IntelliRehab™ use, and this study was approved by the USM Human Research Ethics Committee (HREC); USM/JEPeM/18030172 [20; 24].

A total of eight adults (n=8) with hemiparetic ischemic stroke were recrui-

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ted from Hospital Universiti Sains Malaysia, a suburban tertiary care center for neurological disorders on the east coast of Malaysia. The sample size was determined based on the mean difference (0.25) and standard deviations (0.20) from a previous study calculated using PS software. In the previous study, the FMA score was used as a measure of participant evaluation. With a two-sided significance level of $p<0.05$ and a power $(1-\beta)$ of 0.8, the required sample size was 8 subjects. The selection of subjects was based on purposeful, convenient sampling [21; 25; 26].

IntelliRehab was complemented by customized sensor hardware that gamified physiotherapy with "exergames" as a means of remotely monitoring patient progress and adherence. This remote rehabilitation tool consisted of an intelligent virtual assistant, wireless interaction sensors to capture body movements, and a customized exercise tool designed to facilitate clinical feedback. The new cloud-based platform was designed specifically to track patient data and incorporate multiple inputs, remote monitoring and analytics services. IntelliRehab sessions were conducted at home, where the IntelliRehab tool allowed subjects to perform upper extremity motor training at home as a telerehabilitation setup.

Primary motor function was assessed by FMA, which showed significant improvement after rehabilitation with IntelliRehab. The results of our study are in line with previous studies that demonstrated moderate benefits of Virtual Reality of Broad Range (VRBR) on upper and lower limb body functions and activities compared to standard rehabilitation in stroke patients [20; 24; 27–29].

Randomized control trials (RCTs) have shown that VR was more effective than conventional therapy and significantly more effective than no therapy in improving upper extremity function. VRBR has also been shown to improve Activities of Daily Living (ADL) function compared to more traditional therapy approaches, which supports our current results with the IntelliRehab system. The Fugl-Meyer Assessment (FMA) of IntelliRehab participants showed a significant increase after 3 months of rehabilitation compared to 1 month. This result reflects the effectiveness of the IntelliRehab system in improving functional outcome after 3 months, leading to increased ADLs in stroke patients [30; 31].

On the other hand, secondary motor function was assessed using the SIS scale for stroke patients during IntelliRehab. It had a significant difference in Question-7 (SIS-Q7), which showed a significant increase after 1 month of rehabilitation compared to baseline. The SIS-Q7 measures the patient's ability to use the arm most affected by the stroke. The results are consistent with previous studies that showed similar significance in SIS-Q7 after one month in stroke patients [32].

Factors that influence the success of telerehabilitation. Currently, there are several influential factors. Access to telemedicine services is significantly lower for low-educated social groups (21%) than for groups with higher education (60%) [33]. The use of telemedicine may also be limited for older people, especially when combined with geographic barriers (such as small towns and villages). Numerous studies on telemedicine show the importance of prior patient education and training [34]; however, it is clear that the rapid and hasty introduction of telemedicine also carries a number of threats. Some of them are technological (whether the service is provided on a reliable platform in terms of data security), medical (certain patient problems cannot be solved by telemedicine), while others are legal and ethical (how patients can be transferred to definitive treatment), therapeutic (with telemedicine, how to mitigate side effects and compensate for missing patient safety standards) [35]. Another important task is to establish proper quality assurance. Even countries that have been integrating telemedicine into their healthcare system for more than 15 years (Australia, United States) need to constantly improve the relevant rules. In the United States, the practice of telemedicine is subject to licensure, and some states require a professional exam. Defining the legal and ethical framework is also vital, as it is also related to the issue of patient safety and patient care management. International experience shows that important steps have also been taken in the fields of urology, dermatology, diabetes, and pediatrics to make better use of telemedicine [36; 37].

Commercial and clinical value of telerehabilitation. Despite regulatory changes, the digital healthcare sector saw a record $8.1 billion in investments in 2018. A recent change to the Medicare fee schedule that allows physicians to bill for time spent managing and interpreting remote monitoring data (e.g., electrocardiogram, blood pressure, and glucose monitoring) to treat chronic conditions provides an incentive for clinicians to use mobile health data. However, there are no standard models for who should pay for mobile health technologies that are recommended or prescribed to patients. In clinical trials, decent ralized clinical trials use digital biomarkers as endpoints and replace in-person study procedures with virtual and mobile procedures. Apple's ResearchKit and Android's ResearchStack, mobile research platforms that facilitate large-scale virtual recruitment and evaluation, are expanding the reach of clinical trials, similar to the impact of mobile health on clinical care [38–40].

Conclusions

Mobile health technologies are evolving from descriptive monitoring tools todigital diagnostics and therapies that combine tracking with behavioral and other interventions to directly impact health outcomes. Key challenges include identifying and validating meaningful digital biomarkers, regulating and paying for mobile health technologies, and integra ting them into advanced care. Clearer articulations of how mobile health technologies can directly impact clinical outcomes are needed, as well as more rigorous assessments of clinical effectiveness.

It is possible that mobile health technologies can cause harm. Concerns about digital surveillance are not unique to mobile health, but health-related risks can be mitigated through increased digital literacy among patients, ethical codes of conduct for mobile health developers and regulators, and transparency and accountability in how healthcare organizations deploy mobile devices. The transformative potential of mobile health compels clinicians to play an active role in ensuring that this new frontier is safe, fair, and equitable for all patients.

There is no **conflict of interest**.

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АКТУАЛЬНОСТЬ СОВРЕМЕННОЙ ДИСТАНЦИОННОЙ РЕАБИЛИТАЦИИ (обзор литературы)

Дистанционная реабилитация – это инновационный подход, позволяющий пациентам получать медицинскую поддержку и реабилитационные услуги удобным и безопасным способом в собственном доме или вдали от медицинского учреждения. Дистанционная реабилитация может быть использована для широкого спектра медицинских состояний и проблем, включая физическую терапию, реабилитацию после травм или операций, управление болью, реабилитацию после инсульта, болезни Паркинсона и других неврологических заболеваний, пульмональную реабилитацию для больных хронической обструктивной болезнью, а также психологическую поддержку и консультирование. Этот подход может включать использование видеосвязи, мониторинга физиологических показателей, мобильных приложений и сенсоров для измерения прогресса и наблюдения за пациентом. Дистанционная реабилитация оказывается особенно полезной в ситуациях, когда пациентам тяжело или невозможно физически посещать медицинское учреждение, например из-за ограничений в двигательной активности, отдаленных географических расположений или эпидемиологических обстоятельств. Дистанционная реабилитация имеет как положительные, так и отрицательные стороны. Позитивные стороны: доступность – позволяет пациентам получать необходимую помощь вне зависимости от местонахождения; удобство – получать реабилитационные услуги в удобное для них время и в удобном месте; стоимость – может быть экономически более выгодной, поскольку она уменьшает расходы на поездки и проживание пациентов. Негативные стороны: отсутствие прямого контакта; ограниченные возможности – некоторые виды терапии, требующие руководства или коррекции со стороны специалиста, могут быть менее эффективны в отдаленном формате; технологические проблемы. Важно учитывать эти положительные и отрицательные аспекты дистанционной реабилитации при принятии решения по ее использованию. Конкретные обстоятельства и потребности пациента могут оказывать влияние на эффективность этого подхода к реабилитации. Дистанционная реабилитация является перспективным направлением в медицине, ведь позволяет повысить доступность и удобство получения реабилитационных услуг для пациентов. Она также может способствовать уменьшению нагрузки на медицинские учреждения и снижению затрат на организацию реабилитационных программ.

Ключевые слова: *реабилитационные технологии, реабилитационные услуги, мобильные технологии, положительные и негативные аспекты.*

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АКТУАЛЬНІСТЬ СУЧАСНОЇ ДИСТАНЦІЙНОЇ РЕАБІЛІТАЦІЇ (огляд літератури)

Дистанційна реабілітація – це інноваційний підхід, який дозволяє пацієнтам отримувати медичну підтримку та реабілітаційні послуги зручним і безпечним способом у власному домі або віддалено від медичного закладу. Дистанційна реабілітація може бути використана для широкого спектру медичних станів і проблем, включаючи фізичну терапію, реабілітацію після травм або операцій, управління болем, реабілітацію після інсульту, хвороби Паркінсона та інших неврологічних захворювань, пульмональну реабілітацію для хворих на хронічну обструктивну хворобу легень, а також психологічну підтримку та консультування. Цей підхід може включати в себе використання відеозв'язку, моніторингу фізіологічних показників, мобільних додатків та сенсорів для вимірювання прогресу та спостереження за пацієнтом. Дистанційна реабілітація виявляється особливо корисною в ситуаціях, коли пацієнтам важко або неможливо фізично відвідувати медичний заклад, наприклад, через обмеження в руховій активності, віддалені географічні розташування або епідеміологічні обставини. Дистанційна реабілітація має як позитивні, так і негативні сторони. Позитивні сторони: доступність – дозволяє пацієнтам отримувати потрібну допомогу незалежно від місцезнаходження; зручність – отримувати реабілітаційні послуги в зручний для них час і у зручному місці; вартість – може бути економічно вигіднішою, оскільки вона зменшує витрати на поїздки та проживання пацієнтів. Негативні сторони: відсутність прямого контакту; обмежені можливості – деякі види терапії, які вимагають керування або корекції з боку фахівця, можуть бути менш ефективними у віддаленому форматі; технологічні проблеми. Важливо враховувати ці позитивні та негативні аспекти дистанційної реабілітації при прийнятті рішення про її використання. Конкретні обставини і потреби пацієнта можуть впливати на ефективність цього підходу до реабілітації. Дистанційна реабілітація є перспективним напрямом в медицині, адже вона дозволяє підвищити доступність та зручність отримання реабілітаційних послуг для пацієнтів. Також вона може сприяти зменшенню навантаження на медичні заклади та зниженню витрат на організацію реабілітаційних програм.

Ключові слова: *реабілітаційні технології, реабілітаційні послуги, мобільні технології, позитивні та негативні аспекти.*

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