Telerehabilitation of Post-Stroke Patients with Motor Function Disorders: A Review

V. A. Nikolaev[a, b], *****, **O. G. Safonicheva**[b], ******, and **A. A. Nikolaev**[c], *******

[a] *Pirogov Russian National Research Medical University, Moscow, 117997 Russia*
[b] *Sechenov First Moscow State Medical University, Moscow, 119991 Russia*
[c] *National University of Science and Technology "MISiS," Moscow, 119049 Russia*
*e-mail: managervit@mail.ru
**e-mail: safonicheva.o@mail.ru
***e-mail: nikolaevopr@mail.ru

Abstract—Stroke is the main reason for disabilities of increasing geriatric population. It affects brain and motor function domains significantly reducing the life quality. Recent coronavirus pandemic raised a question on changing approaches to deliver post-stroke rehabilitation services to geriatric patients due to their high risk of serious illness. This paper presents an overview of current telerehabilitation approaches for motor function recovery and balance training of post-stroke patients. We used papers from peer-reviewed medical journals on stroke telerehabilitation. The review showed exergames, virtual reality (VR), web-platforms, and applications are extensively used in rehabilitation programs to gain clinical outcomes among geriatric stroke patients. Findings indicate telerehabilitation improves older patients' functional ability via systematic training, positively affecting their life quality. The treatment therapy of older adults using telerehabilitation can be organized synchronously and asynchronously in home-based environment or in-clinic conditions. Telerehabilitation can be used as complementary therapy or as an alternative to conventional treatment. However, further research is required to test a variety of telerehabilitation systems using larger samples of post-stroke geriatric patients.

INTRODUCTION

Most post-stroke patients suffer from motor function disorders [6, 15, 30]. Some of them undergo conventional rehabilitation programs to mitigate negative effects of stroke improving motor functioning [11, 26]. Despite conventional treatments a majority of patients remains out of daily life activities, needing assistance and suffering from reduced quality of life [1, 16]. This is due to insufficient healthcare management, the lack of access to rehabilitation services, remote living, and health status [7, 13, 26]. The recent coronavirus pandemic results in changing approaches to rehabilitation services delivery, particularly to the geriatric patients, due to their high risk of serious illness [18]. Moreover, geriatric stroke patients tend to discard high intensive conventional rehabilitation. To overcome an increasing problem of post-stroke patients rehabilitation and induce the healthcare system burden a telerehabilitation can be implemented. This paper is aimed at reviewing the current practices on post-stroke telerehabilitation of patients with motor function disorders.

UPPER AND LOW EXTREMITIES

S.C. Cramer et al. [5] report on recent advances of telerehabilitation in the management of adults with motor impairments after stroke. The research presents findings of a randomized, assessor-blinded, noninferiority trial in 124 patients (mean age 61 ± 14 years) across 11 sites in the United States which was carried out by the Health StrokeNet Telerehab Investigators. Post-stroke patients with motor impairments affecting the upper extremities were randomized to in-clinic or telerehabilitation treatments. All patients were trained during 6–8 weeks, including 36 treatment sessions. The sessions were equally divided into supervised and unsupervised. Each session consisted of 70 min supervised activities and a 10-min break. The program included the same therapy, exercises, and stroke education provided for both offline and online groups of patients. Video conferencing sessions included 12 gaming devices (trackpad or PlayStation Move controller, Sony), providing functional tasks along with augmented reality.

The findings imply that telerehabilitation is not inferior to in-clinic rehabilitation therapy improving arm motor function and stroke knowledge of the individuals. Improvements in Fugl-Meyer Arm Motor Scale (FM) score and stroke knowledge were observed 4 weeks after the research was completed. Moreover, the participants showed improvements in motivation. Interestingly, that in-clinic and telerehabilitation groups accomplished similar gains in FM results. Also, findings showed similar gains for patients' compliance and education measures, management of upper motor deficits after stroke for tele- and in-clinic rehabilitation. Interestingly, the engagement of the patients through in-clinic rehabilitation was slightly higher as compared to telerehabilitation. The authors underline an advantage of telerehabilitation as it can be used during lockdown or related cases. However, the limitations relate to insufficient internet access and the lack of equipment.

T. Szturm et al. [27] introduced a computer-aided and game assisted telerehabilitation platform for home-based upper extremities rehabilitation after stroke. It included a miniature, wireless inertial-based computer mouse which linked physical movements with interactive computer games. The system made it possible for the patients to take a task-specific practice of object handling and manipulation to overcome difficulties in gross and fine motor skills during playing computer games. More importantly, the mouse-device was installed in physical exercise objects (plastic ball, soccer ball, coffee mug, etc.) given by therapists to train motor function through the participant's engagement with related computer games. Ten individuals (mean age 58 ± 12 years) were involved in the study. Initially, the participants who had a single stroke onset between 4 months and 2 years attended 3−4 treatment sessions (duration of each session was 45−60 min) at a clinical rehabilitation research facility of the University of Manitoba. Hand-arm exercises were presented to individuals to teach them doing the game-assisted exercises independently at home. Also, participants were aware of how to perform the various tasks with specific arm segment motions and to prevent associated movements. Furthermore, individuals were trained to use computer games and an inertial mouse.

Post-stroke individuals used well-designed interactive games improving motor activities of upper extremities via motivating repetitive task practice. A personal rehabilitation program was formed for each participant and consisted of exercises performed four times a week for 4 months with the daily duration of the exercise of 20−30 min. The weekly adjustments of the rehabilitation program and communication among participants and therapists were organized through email/telephone services. Furthermore, some participants sent video clips to research staff to monitor the progress and make changes in their personal rehabilitation programs.

The Wolf Motor Function Test (WMFT), a computerized performance-based assessment of specific object manipulation tasks requiring a combination of shoulder, elbow, wrist and finger motion were used in quantitative analysis. Retention rate and compliance were used to evaluate the feasibility, since semi-structured interviews were used to assess the acceptability of the telerehabilitation program. The findings showed the feasibility of the gaming system and improvements of upper extremities function of post-stroke patients. Eight of 10 participants fully complied with the 16-week exercise program, since two participants faced difficulties with computer operations and dropped out of the program. Observations also showed the accessibility of rehabilitation services for patients living in rural areas with limited therapy services and their availability to take regular telerehabilitation at most convenient times. However, there were the following limitations. First, the program required a computer, a wireless inertial-based computer mouse and a source of common computer games. Second, a basic knowledge of computer operation was needed. Finally, several important activities: writing, doing up buttons, tying shoelaces and cutting food as well as practicing tasks that require only linear motion were impossible to implement due to technical limitations of the system.

Q. Qiu et al. [21] investigated upper extremities telerehabilitation via a home-based virtual rehabilitation system, which was placed in homes of 15 patients with chronic stroke. The VR training application ran video games on the computers of post-stroke individuals using a cross-platform. To capture motions of arms and hands of the patients the leap motion controller was used. It is consisted of 2 cameras and 3 infrared LEDs. The system made it possible for patients to interact and control the games without wearable sensors. Specifically, they moved their upper extremities. Moreover, an anti-gravity arm device was used for proximal arm impairments patients allowing them posing and transporting their hands. The VR-based system used the online algorithms processing and controlling kinematic data. In particular, it used twenty-two degrees of freedom for the wrist and hand. They used 12 games to train a specific movement pattern. In general, the games were tailored at whole arm, hand, elbow-shoulder, and wrist activities. The post-stroke patients tested the VR system every weekday for at least 15 min for 3 months. On average, they spent 13.5 h using VR telerehabilitation. In addition, remote clinical monitoring and limited technical support were provided. The findings showed a mean increase of 5.2 (SEM = 0.69) on the upper extremity FM among persons who were involved in the study. Moreover, improvements in six measurements of hand kinematics were also observed. The findings demonstrated that VR telerehabilitation improved the upper extremity function of chronic stroke patients. Also, the therapy was delivered in the safety environment with minimal supervision.

The results of a combination of modified Constrained Induced Movement Therapy (mCIMT) program using face-to-face sessions were presented by M.A. Smith et al. [24]. Specifically, 8 individuals aged 18−75 participated in the study, in which among several indispensable conditions for the patients were living in their homes, having internet access and video conferencing devices. The web-based software (Google Hangout, Adobe Connect) was installed onto patients' computers. Also, they were equipped with a tool kit containing typical physical objects for fine/gross motor movements. During online sessions with a therapist the post-stroke individuals used those objects to train their extremities. The internet-based telerehabilitation sessions lasted for an hour with the intensity of two times a week during six-week period. The assessment of the progress and functional use of the upper extremity of each participant was based on the results of WMFT, FM, Motor Activity Log (MAL) and Functional Independence Measure (FIM) tests at both baseline and after the study was finished. A positive effect of a combination of mCIMT with telehealth and conventional rehabilitation resulted in functional and quality of use improvements in the hemiparetic upper extremity for low and high functioning participants. Moreover, high attendance rate (84.5%) of telehealth sessions as compared to in-person ones (75.3%) indicated a significant engagement of post-stroke patients in online telerehabilitation. Although research indicates positive effects in upper extremity functioning, there were individuals who struggled with internet access and were unfamiliar with information technology (IT). Authors claim that these obstacles can be overcome with the family support approach.

Y. Chen et al. [3] concluded that videoconferencing motivated patients to stay on track during telerehabilitation as they felt obliged to complete their assignments as compared to traditional rehabilitation where they occasionally missed offline sessions. They carried out a qualitative study of a telerehabilitation system for stroke patients conducting upper limb home-based therapy sessions using therapy games, education, exercises, and videoconferencing with therapists. The study involved 13 patients with subacute phase after stroke who had completed the 6-week telerehabilitation program. It included 36 treatment sessions, which were equally divided to unsupervised and therapist-supervised using videoconferencing. The supervised sessions began with 30-min work with the therapist and then a 40-min self-administered therapy using the telerehabilitation system only was used. In the beginning of each unsupervised sessions there was a 5-min education consisting of prevention, recognition, response, and stroke management issues. Afterwards, the stroke-related games and exercises were performed. The participants via telerehabilitation trained limb functions and cognitive abilities as well as improved emotional well-being. The findings showed the home-based telerehabilitation is convenient with respect to location, time, and travel, reducing efforts of patients and caregivers, enhancing the training dose. Although the participants intend to use telerehabilitation in the future, several drawbacks have appeared for some individuals apart from technical issues and limitations of home space. Specifically, the participants reported that a system should include progress-dependent exercise difficulty to keep them engaged during long-term rehabilitation. Also, visibility of the progress might help the participants to be more motivated and sustain the improvements on a long time basis. Other limitations include insufficient technical support and the lack of training space for home-based training. Study also shows that family members' involvement positively affects the rehabilitation outcomes improving sustainability. Interestingly, the researchers discussed that personal telerehabilitation plan designing, engagement of individuals, and design development for the home-based environment are possible means facilitating stroke recovery.

A. Perrochon et al. [20] reviewed the data on using exergames by individuals with neurological diseases for upper- or lower-limbs rehabilitation at home. Researchers and therapists supervised the patients and monitored their performance using home visits, phone and video calls, emails, or via secured websites. According to observations, exergames showed a feasible alternative to a conventional rehabilitation of individuals with neurological diseases in the home-based environment. Although positive effects of exergames were observed, the authors underline that more research on optimal dose training is needed. Apparently, an intervention period of telerehabilitation was that one of a minimally required dose of telerehabilitation that was suggested to be of 15−16 hours. Another recommendation was using custom-designed exergames to achieve higher effectiveness of telerehabilitation through targeted specific clinical features of neurological diseases. The task-specific approach increasing diversity of exercises and daily living activities seems to be effective.

J.W. Hung et al. [10] investigated the telerehabilitation of thirty-three patients with chronic hemiplegic stroke via a randomized controlled single-blinded study. The participants were subdivided into an experimental group utilizing telerehabilitation through exergames and a control group using traditional therapist-based treatment. The research lasted 3 months and consisted of 30-min sessions 2−3 times a week. FM, WMFT, MAL tests, Pittsburgh participation scale and an accelerometer were used to assess the performance and engagement of patients. The experimental group underwent 3−4 games per session, in total 8 games were tested including 2 bimanual and 8 unimanual. Moreover, the difficulty level of each game was adjusted by the therapist according to abilities and needs of the participants, demonstrating a personalized approach. Furthermore, the therapist instructed the participants and monitored their safety.

The therapist also supervised the personal training of participants in the control group using a variety of unilateral and bilateral upper extremity exercises with respect to patients' personal abilities and needs, giving personal feedback and taking corrective actions. The findings indicate similar outcomes for both groups even at three months follow-up. However, the total activity counts of the affected upper extremity and the participation level were significantly higher in the exergames group than those in the control group. Findings demonstrate the feasibility of exergames rehabilitation and improvements in stroke recovery as compared to therapist-based training. Although there were no significant side effects during the interventions, most participants who used exergames reported the upper extremity soreness after training, which subsided spontaneously without additional treatment. The control group had no side effects. Furthermore, exergames can be served as a cost-effective and easy to set-up complementary therapy to conventional treatment, potentially decreasing the workload of therapists. Another study by K.M. Triandafilou et al. [29] found a home-based VR is a promising therapy for arm motion improvements with a high willingness of post-stroke survivors to perform the training for at least 2−3 days a week.

M. Park et al. [19] tested a VR-based device, consisted of a board, a forearm-supported controller, a display, and an android personal computer (PC). The system prevents antigravity muscle facilitation by incorporating two-dimensional planar exercises with gravitational support, giving opportunity to participate in rehabilitation for patients who cannot perform the hard three-dimensional exercises due to gravity. The findings revealed that VR-based treatment is effective and can be used as complementary therapy with a more pronounced effect. Promising improvements in active range of motion of the proximal upper limbs support the findings. Similar solution was obtained in the study [8] although the system contained a portable cost-effective robotic system ArmAssist (AA). It was based on the Antari Home Care platform for supervising, customizing, and managing telerehabilitation of the patients remotely. Also the system used exergames approach. In general, the home-based rehabilitation system required a table space of 110 × 68 cm and Wi-Fi access. During the games the sensors of the system measured self-directed active movements of the patient while the rehabilitation device was fastened on the forearm. Nine patients used the system for 3 weeks, including a week of supervised training at the Maimonides Biomedical Research Institute in Córdoba (Spain), one more week of a homed-based supervised rehabilitation, and one week with remote supervision and support. The usability of the system was proved showing moderate clinical improvements, safety, and motivation of patients.

The Australian study [22] involved a VR rehabilitation of 21 patients aged 42−94 years old with sub-acute unilateral stroke and upper extremity dysfunctions. They used VR in addition to traditional therapy and compared it to stand-alone conventional treatment. The findings observed a significantly larger magnitude and rate of improvements in motor hand function and cognitive function using VR than conventional therapy.

Promising results of telerehabilitation interventions improving post-stroke outcomes in Ghana were presented by F.S. Sarfo et al. [23]. Twenty post-stroke survivors aged 54.6 ± 10.2 years used smartphones with preinstalled 9zest Stroke Rehab application and internet access. Specifically, the application can be customized to fulfill specific requirements and needs of the individuals to recover from stroke [28]. A personalized goal-tailored telerehabilitation program was implemented 5-days a week for 3 months, each session lasted 30−60 min. The daily physical therapy exercises were administrated remotely and video-recording of exercises was also granted using a smartphone system. Moreover, they used a weekly telephone conferencing with a therapist to support rehabilitation. Furthermore, post-stroke patients underwent a standardized rehabilitation program aimed at improving mobility through lower and upper limb strengthening exercises, dexterity enhancing fine motor movements, walking endurance, and balance training using standing and seating activities. Findings demonstrated improvements in scores of medical tests, including improvements in stroke levity scale scores. As compared to a baseline at month three the modified Rankin score decreased from 2.2 ± 0.6 to 1.8 ± 0.7, while the mean baseline Barthel's index and Montreal cognitive assessment (MoCA) score increased from 94.4 ± 6.4 to 96.1 ± 6.4% and from 18.2 ± 4.3 to 22.2 ± 7.6 respectively. The findings prove the feasibility and cost-effectiveness of m-health telerehabilitation with a high level of participants' satisfaction.

This is in line with a study [25] underlining that post-stroke survivors undergoing home based rehabilitation are more active in their homes in the first week after discharge. Moreover, they spend on average 12 more minutes walking and 45 more minutes upright as compared to their activities during their last week spent in a rehabilitation hospital.

BALANCE PROBLEMS

J.P. Held et al. [9] investigated a home-based rehabilitation system (REWIRE) for balance and gait training of 16 post-stroke individuals with first stroke onset (3−74 months) and mild to moderate impairments. The telerehabilitation platform was consisted of the patients' system, the hospital and networking stations. The home-based system included a laptop, the Microsoft Kinect camera, and the Tyromotion balance board. During rehabilitation session (10−40 min/day) each patient performed exergames standing in front of the TV screen, moving in real-time, and interacting with digital avatar in VR environment. Also, some exerga-

mes required a force plate for tracking the centre of pressure. Additionally, there was a virtual therapist, endowed with an artificial intelligence based on a fuzzy control system. The virtual therapist guided the patients, including both advices and encouragement, summarizing the results in the end of each session. Moreover, the patient station logged the gaming data, recorded the patients' performance, and sent it to the hospital station at the end of the session. The clinicians instructed the fuzzy system before starting the therapy, used the hospital station to assess the patients' performance and reviewed the therapy outcomes, configured and scheduled the sessions. The findings showed that REWIRE system feasible supporting the autonomous home-based rehabilitative therapy.

A randomized pilot trial implementing telerehabilitation for balance training of 10 post-stroke patients was undertaken in the research [4]. Specifically, multiple exergames (balancing and standing up, single-leg exercises, and weight shifting) were used to customize rehabilitation of post-stroke inpatients aged 33—65. The rehabilitation system included an LCD screen, a computer, an RGB camera, and Wii Balance Board. The system required 6 m^2 of space to perform exercises. In addition to neurotherapeutic treatment, the stroke survivors underwent three different exergames with overall intensity of 15 min/day during 5 days. When training, each participant stood on the board in front of the LCD screen performing different motions and exercises depending on the game plan. Although the patients performed their training on their own a physiotherapist supervised the rehabilitation process during the session ensuring safety and preventing potential accidents. The rehabilitation system provided calm and relaxed conditions for post-stroke individuals' rehabilitation with a variety of exergames and adjustable levels of difficulty to personalize the rehabilitation process. Clinical data were collected through Clinical Test for Sensor, Romberg, Sharpened Romberg, Timed Up and Go tests, 10 m Walk Test, and Four Square Step Test, monitoring a center of pressure during studies. The findings imply that exergames rehabilitation is similar to conventional rehabilitation in terms of clinical outcomes, having the advantage of the accessibility of the objective and measurable information relating to the center of the press. Moreover, selecting individualized exergames at the stage of planning of rehabilitation allows adjusting regimen and improving balance training outcomes.

P.I. Burgos et al. [2] tested smartphones, inertial sensors, and a cloud database to improve the balance of six post-stroke patients using the exergames telerehabilitation system. The patients with early subacute stroke (6—8 weeks after stroke) in addition to conventional treatment at a hospital (Chile) were involved in telerehabilitation. Their home-based telerehabilitation using smartphones lasted for a month and consisted of nine 30-min sessions. Before the program, the patients and caregivers were instructed on technical (placement of sensors, their calibration, exergames adjustment, and performance) and safety issues. The system consisted of two wireless inertial movement sensors positioned at the lumbar level and the anterior thigh of the paretic side of each patient and was connected to an Android-based smartphone. The participants interacted with a custom-developed Android application performing exergames. Moreover, the difficulty level of exergames was adjusted by the patients depending on their progress. The telemedicine interventions were conducted by a physical therapist who daily contacted each participant to keep standard interaction and increase protocol adherence. To monitor the rehabilitation process the therapist either connected to the web-platform and observed daily games scores according to a timetable of the session or analyzed the results at any convenient time after training was completed. Furthermore, the System Usability Scale (SUS) was implemented to measure a user experience. To train balance the participants performed tasks through exergames that were based on smartphones controlled by body motions. The findings revealed significant improvement in the Berg Balance Scale (11.3 ± 3.5 points), Mini-BESTest (8.3 ± 3.01 points), and in the Barthel scale (17.5 ± 9.87 points), although the improvements of Barthel and Berg scales were statistically higher for the telerehabilitation of patients than for the control group that was undergoing a traditional rehabilitation in a hospital. Positive effects of tele-interventions can be attributed to that the telerehabilitation took place at the early subacute post-stroke stage with the high training dosage. Moreover, the smartphone-based rehabilitation system demonstrated high values of usability on SUS that was 87.5 ± 11.61. Feasibility of the proposed exergames system with low costs as a complementary therapy was confirmed demonstrating significant improvements of the balance of stroke patients. Despite the system showed a solid performance on small groups of patients, further research on large groups is needed.

The efficacy of motor-cognitive rehabilitation of individuals with chronic stroke using exergames improving balance control and cognition was evaluated by L. Kannan et al. [14]. In their randomized controlled trial, twenty-four patients participated in a highly intensive 6-week rehabilitation program. Specifically, 12 patients underwent motor-cognitive exergames treatment since the rest of the individuals were assigned to conventional rehabilitation. The experimental group used Wii-fit games in conjunction with cognitive tasks. During the training session, each person stood on a balance board sensing the symmetry of the body weight distribution. Also, the participants were motivated by an assistant to perform both exergames and cognitive tasks. The scores that appeared at the end of the game provided instant feedback and then a more difficult level of the exergames and cognitive tasks was adjusted to sustain progress. The results showed the patients in motor-cognitive exergame

group improved motor and cognition since those in the conventional rehabilitation group showed improvements of motor function only. The authors recommend clinical implementation of exergames rehabilitation settings to improve balance control and cognition. These findings collocate to G. Morone et al. [17] highlighting the inextricable connection between motor and cognitive systems. They underline the importance of motor-cognitive rehabilitation employing innovative technological devices.

Recently M. Junata et al. [12] carried out a randomized controlled trial to examine the telerehabilitation improving balance recovery for stroke fall prevention. Specifically, 30 elderly chronic patients from Hong Kong Stroke Association were assigned into experimental and control groups. The telerehabilitation system included the Kinect-based platform. It allowed patients performing exercises standing in front of the screen. The system tracked their 3D movements and timing. In general, the patients required performing extremities movements in 22 different directions as far and as quickly as possible. During the training session the patients wore safety harness and performed 4 repetitions during 1 hour session. The control group performed conventional balance training exercises. Each session lasted 1 hour and included 3 repetitions. According to the study design the patients underwent 3 sessions per week for seven weeks. The findings showed the telerehabilitation is as effective as conventional treatment improving balance performance and motor function, and reducing fall risks. Specifically, the patients improved balance control (Berg Balance Scale) from 49.13 to 52.75 ($p = 0.001$) and gait control (Timed-Up-and-Go Test) from 14.66 to 12.62 s ($p = 0.011$). The study also showed the potential of balance training for home-based telerehabilitation.

A majority of studies reviewed proves feasibility of telerehabilitation for stroke survivors and at least similar or even more pronounced effects of telerehabilitation on motor function, engagement, and motivation, granting access to rehabilitation services of a large number of patients with immobility or living in remote areas, leading to sustainable recovery from stroke. To implement telerehabilitation conventional equipment (computers, laptops smartphones, etc.) that stroke survivors already own and use for daily activities can be used. Moreover, indigent patients can be provided with devices by healthcare or social care organizations. Furthermore, all of the patients, if necessary, can be equipped with other hi-tech rehab equipment and software, including exergames, VR, online conferencing applications, and educational materials.

Telerehabilitation programs are quite flexible and can be carried out in-clinic or in patients' homes both online using the internet connection and utilizing up-to-date rehab web-based platforms and services or off-line with preinstalled software and training programs to prevent dependency of rehabilitation on internet affordability. In this context, supervised or unsupervised training is implemented to adjust rehabilitation programs. To achieve significant outcomes in rehabilitation a systematic training with a specific dose is required. Moreover, monitoring of the progress of treatment regimen is vital, which can be obtained online via web-based services and platforms, wearable e-health devices, videoconferencing, and telephone calls with or without the involvement of therapists. Alternatively, offline visits of clinicians or medical staff, delivering email and e-messages with rehabilitation data, including a video recording of patients' performance can be used to monitor the progress. Delivering rehabilitation using telehealth is vital for homebound geriatric patients.

Systematic videoconferencing with a therapist or other feedbacks from healthcare professionals positively affect patients as they feel visiting a doctor and they are in charge for their rehabilitation outcomes, and hence, must be prepared to keep on training, improving motivation and enhancing recovery. Interestingly, telerehabilitation significantly enhances self-motivation and engagement of post-stroke patients as compared to conventional rehabilitation, especially through exergames where the patients are involved in keeping on track and monitoring the progress to obtain continuing improvements.

The advantage of exergames and VR over conventional rehabilitation means that treatment occurs 24/7 at a self-paced training regimen at the most convenient time for patients. This also includes instant and continuous feedback between the rehabilitation system and the patient, obtaining measurable information, motivating the post-stroke survivors to keep training and improving their state of health and stroke recovery. Although early rehabilitation is beneficial with respect to outcomes, it seems the telerehabilitation is also applicable at different stroke stages.

More importantly, the telerehabilitation programs can be adjusted to the needs of post-stroke patients depending on their level of health and mobility. Furthermore, the telerehabilitation can be delivered in parallel to conventional in-clinic rehabilitation as adjunctive therapy, and used as a therapy after hospital discharge or as a prolonged home-based self-rehabilitation program.

Apparently, the number of individuals with motor function disabilities and balance problems due to stroke will increase significantly over future decades because of demographic growth changes. Since a majority of post-stroke individuals across the globe cannot access conventional rehabilitation facilities for improving their motor function due to immobility, health status, lack of rehabilitation services and clinicians, distant living from medical centers, pandemic restrictions, or economical reasons, there is a growing post-stroke population that could benefit from the use of telerehabilitation.

Despite generalization of telerehabilitation, predictive and preventive treatment seems beneficial for patients without access to face-to-face rehabilitation, recurring prevention of stroke and significantly decreasing mortality and psychological drawbacks, preventing social isolation and physiological diseases. Specifically, personalization meets the needs of the patients, customizing rehabilitation programs with respect to disease consequences, age, health status, difficulty level, and intensity of treatment. Duration and intensity of the programs, sets of exercises, interactions between patients, rehabilitation systems and therapists are varied and must be tailored to meet the clinical outcomes and patients' needs.

Also, stroke survivors play an important role in the rehabilitation process, and hence, their awareness, involvement and engagement in the training process are essential to gain self-motivation leading to significant improvements in stroke recovery. Moreover, their relatives, carers and healthcare professionals should also be involved through education and motivation sessions.

Finally, telerehabilitation allows implementing stroke recovery during a pandemic or under other restrictions, preventing infection, inactivity and social isolation, making geriatric patients more confident and independent, preventing psychological drawbacks, and improving their life quality.

Although telerehabilitation showed improvements in post-stroke recovery, there were also limitations. First, the lack of equipment and software, which partially can be overcome using conventional equipment and freeware software or with the support of healthcare organizations. Then, a deficit of proficiency in digital technologies and education arises for both post-stroke patients and healthcare professionals, which can be managed by utilizing easy-to-learn equipment, friendly interface, clear instructions or short courses, and trials before and at the beginning of telerehabilitation programs. Importantly, to overcome differences in technical and digital proficiency for geriatric patients the telerehabilitation equipment and software can become more intuitive and easy to learn.

Since most studies underline the convenience of home-based exercises, some observations report the lack of space for exercises at patients' homes, although, they can be performed outdoors or with the support of relatives and carers. Moreover, substantial work remains to establish the optimal dose and intensity of telerehabilitation treatment. Also, the side effects should be further researched. Finally, most reviewed studies used small samples, and hence, future research should involve large samples of post-stroke patients to verify clinical outcomes.

CONCLUSIONS

The results of our review confirm prior literature underlining the role of telerehabilitation of post-stroke survivors. The telerehabilitation is feasible improving clinical outcomes of post-stroke patients. Apparently, technological and methodological improvements are seemed to result in a healthcare paradigm shift to implement cost-effective remote delivery of healthcare system, meeting the requirements of post-stroke individuals and granting access to rehabilitation services. Further research should be aimed at testing telerehabilitation systems for larger numbers of geriatric post-stroke patients and developing the most effective programs of rehabilitation under different conditions. Future intentions of researchers, healthcare professionals and stakeholders should be focused on implementing cutting edge solutions for sustainable improvements in health status and quality of life of post-stroke patients.

Within the next five years, a significant expansion in methods and devices of telerehabilitation is anticipated. Advanced methods and equipment, such as artificial intelligence, the internet of things, robotics and haptic devices will also be embedded in rehabilitation programs of post-stroke patients, reducing workload of therapists and clinicians and associated healthcare costs.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflicts of interest.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study.

REFERENCES

1. Bayley, M.T., Hurdowar, A., Richards, C.L., et al., Barriers to implementation of stroke rehabilitation evidence: Findings from a multi-site pilot project, *Disabil. Rehabil.*, 2012, vol. 34, no. 19, pp. 1633−1638.
https://doi.org/10.3109/09638288.2012.656790
2. Burgos, P.I., Lara, O., Lavado, A., et al., Exergames and telerehabilitation on smartphones to improve balance in stroke patients, *Brain Sciences,* 2020, vol. 10, no. 11, p. 773.
https://doi.org/10.3390/brainsci10110773
3. Chen, Y., Chen, Y., Zheng, K., et al., A qualitative study on user acceptance of a home-based stroke telerehabilitation system, *Top. Stroke Rehabil.*, 2020, vol. 27, no. 2, pp. 81−92.
https://doi.org/10.1080/10749357.2019.1683792
4. Cikajlo, I., Rudolf, M., Mainetti, R., and Borghese, N.A., Multi-exergames to set targets and supplement the intensified conventional balance training in patients with stroke: a randomized pilot trial, *Front. Psychol.*, 2020,

no. 11, p. 572.
https://doi.org/10.3389/fpsyg.2020.00572

5. Cramer, S.C., Dodakian, L., Le, V., et al., Efficacy of home-based telerehabilitation vs. in-clinic therapy for adults after stroke: a randomized clinical trial, *JAMA Neurol.,* 2019, vol. 76, no. 9, pp. 1079−1087.
https://doi.org/10.1001/jamaneurol.2019.1604

6. Donkor, E.S., Stroke in the 21st century: a snapshot of the burden, epidemiology, and quality of life, *Stroke Res. Treat.,* 2018, vol. 3, pp. 1−10.
https://doi.org/10.1155/2018/3238165

7. Enderby, P., Pandyan, A., Bowen, A., et al., Accessing rehabilitation after stroke—a guessing game?, *Disabil. Rehabil.*, 2017, vol. 39, no. 7, pp. 709−713.
https://doi.org/10.3109/09638288.2016.1160448

8. Guillén-Climent, S., Garzo, A., Muñoz-Alcaraz, M.N., et al., A usability study in patients with stroke using MERLIN, a robotic system based on serious games for upper limb rehabilitation in the home setting, *J. Neuroeng. Rehabil.*, 2021, vol. 18, no. 1, p. 41.
https://doi.org/10.1186/s12984-021-00837-z

9. Held, J.P., Ferrer, B., Mainetti, R., et al., Autonomous rehabilitation at stroke patients home for balance and gait: safety, usability and compliance of a virtual reality system, *Eur. J. Phys. Rehabil. Med.*, 2018, vol. 54, no. 4, pp. 545−553.
https://doi.org/10.23736/S1973-9087.17.04802-X

10. Hung, J.W., Chou, C.X., Chang, Y.J., et al., Comparison of Kinect2Scratch game-based training and therapist-based training for the improvement of upper extremity functions of patients with chronic stroke: a randomized controlled single-blinded test, *Europ. J. Phys. Rehab. Med.*, 2019, vol. 55, no. 5, pp. 542−550.
https://doi.org/10.23736/S1973-9087.19.05598-9

11. Johnson, W., Onuma, O., Owolabi, M., and Sachdev, S., Stroke: a global response is needed, *Bull. World Health Organ.*, 2016, vol. 94, no. 9, pp. 634−634A.
https://doi.org/10.2471/BLT.16.181636

12. Junata, M., Cheng, K.C., Man, H.S., et al., Kinect-based rapid movement training to improve balance recovery for stroke fall prevention: a randomized controlled trial, *J. Neuroeng. Rehabil.*, 2021, vol. 18, no. 1, p. 150.
https://doi.org/10.1186/s12984-021-00922-3

13. Kalavina, R., Chisati, E., Mlenzana, N., and Wazakili, M., The challenges and experiences of stroke patients and their spouses in Blantyre, Malawi, *Malawi Med. J.*, 2019, vol. 31, no. 2, pp. 112−117.
https://doi.org/10.4314/mmj.v31i2.2

14. Kannan, L., Vora, J., Bhatt, T., and Hughes, S.L., Cognitive−motor exergaming for reducing fall risk in people with chronic stroke: a randomized controlled trial, *NeuroRehabilitation*, 2019, vol. 44, no. 4, pp. 493−510.
https://doi.org/10.3233/NRE-182683

15. Kim, J., Thayabaranathan, T., Donnan, G.A., et al., Global Stroke Statistics 2019, *Int. J. Stroke: Offic. J. Int. Stroke Soc.*, 2020, vol. 15, no. 8, pp. 819−838.
https://doi.org/10.1177/1747493020909545

16. Magwood, G.S., Ellis, C., Nichols, M., et al., Barriers and facilitators of stroke recovery: perspectives from African Americans with stroke, caregivers and healthcare professionals, *J. Stroke Cerebrovasc. Dis.*, 2019, vol. 28, no. 9, pp. 2506−2516.
https://doi.org/10.1016/j.jstrokecerebrovasdis.2019.06.012

17. Morone, G., Spitoni, G.F., De Bartolo, D., et al., Rehabilitative devices for a top-down approach, *Expert Rev. Med. Devices,* 2019, vol. 16, no. 3, pp. 187−195.
https://doi.org/10.1080/17434440.2019.1574567

18. Oh-Park, M., Lew, H.L., and Raghavan, P., Telerehabilitation for geriatrics, *Phys. Med. Rehabil. Clin. N. Am.*, 2021, vol. 32, no. 2, pp. 291−305.
https://doi.org/10.1016/j.pmr.2021.01.003

19. Park, M., Ko, M.H., Oh, S.W., et al., Effects of virtual reality-based planar motion exercises on upper extremity function, range of motion, and health-related quality of life: a multicenter, single-blinded, randomized, controlled pilot study, *J. Neuroeng. Rehabil.*, 2019, vol. 16, no. 1, p. 122.
https://doi.org/10.1186/s12984-019-0595-8

20. Perrochon, A., Borel, B., Istrate, D., et al., Exercise-based games interventions at home in individuals with a neurological disease: a systematic review and meta-analysis, *Ann. Phys. Rehabil. Med.*, 2019, vol. 62, no. 5, pp. 366−378.
https://doi.org/10.1016/j.rehab.2019.04.004

21. Qiu, Q., Cronce, A., Patel, J., et al., Development of the home based virtual rehabilitation system (HoVRS) to remotely deliver an intense and customized upper extremity training, *J. Neuroeng. Rehabil.*, 2020, vol. 17, no. 1, p. 155.
https://doi.org/10.1186/s12984-020-00789-w

22. Rogers, J.M., Duckworth, J., Middleton, S., et al., Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: evidence from a randomized controlled pilot study, *J. Neuroeng. Rehabil.*, 2019, vol. 16, no. 1, p. 56.
https://doi.org/10.1186/s12984-019-0531-y

23. Sarfo, F.S., Adusei, N., Ampofo, M., et al., Pilot trial of a tele-rehab intervention to improve outcomes after stroke in Ghana: a feasibility and user satisfaction study, *J. Neurol. Sci.*, 2018, no. 387, pp. 94−97.
https://doi.org/10.1016/j.jns.2018.01.039

24. Smith, M.A. and Tomita, M.R., Combined effects of telehealth and modified constraint-induced movement therapy for individuals with chronic hemiparesis, *Int. J. Telerehabil.*, 2020, vol. 12, no. 1, pp. 51−62.
https://doi.org/10.5195/ijt.2020.6300

25. Smyth, C., Roberts, D., and Monaghan, K., Poststroke telerehabilitation. The role of telerehabilitation is evolving rapidly, *Pract. Neurol.*, 2020, pp. 59−62.

26. Stinear, C.M., Lang, C.E., Zeiler, S., and Byblow, W.D., Advances and challenges in stroke rehabilitation, *Lancet Neurol.*, 2020, vol. 19, no. 4, pp. 348−360.
https://doi.org/10.1016/S1474-4422(19)30415-6

27. Szturm, T., Imran, Z., Pooyania, S., et al., Evaluation of a game based tele rehabilitation platform for in-home therapy of hand−arm function post stroke: feasibility study, *PM R,* 2021, vol. 13, no. 1, pp. 45−54.
https://doi.org/10.1002/pmrj.12354

28. The 9zest. https://9zest.com/stroke/. Cited April 17, 2021.

29. Triandafilou, K.M., Tsoupikova, D., Barry, A.J., et al., Development of a 3D, networked multi−user virtual reality environment for home therapy after stroke, *Neuroeng. Rehabil.*, 2018, vol. 15, no. 1, p. 88.
https://doi.org/10.1186/s12984-018-0429-0

30. Summary: World report on disability, 2011. https://apps.who.int/iris/handle/10665/70670/. Cited July 27, 2021.