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REVIEW ARTICLE (META-ANALYSIS)

Effectiveness of Technology-Based Distance Physical Rehabilitation Interventions for Improving Physical Functioning in Stroke: A Systematic Review and Meta-analysis of Randomized Controlled Trials

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Abstract

Objective: To study the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning in stroke.

Data Sources: A systematic literature search was conducted in 6 databases from January 2000 to May 2018.

Study Selection: Inclusion criteria applied the patient, intervention, comparison, outcome, study design framework as follows: (P) stroke; (I) technology-based distance physical rehabilitation interventions; (C) any comparison without the use of technology; (O) physical functioning; (S) randomized controlled trials (RCTs). The search identified in total 693 studies, and the screening of 162 full-text studies revealed 13 eligible studies.

Data Extraction: The studies were screened using the Preferred Reporting Items for Systematic Reviews and Meta-analysis guidelines and assessed for methodological quality and quality of evidence. Meta-analysis was performed if applicable.

Data Synthesis: A total of 13 studies were included, and online video monitoring was the most used technology. Seven outcomes of physical functioning were identified—activities of daily living (ADL), upper extremity functioning, lower extremity functioning, balance, walking, physical activity, and participation. A meta-analysis of 6 RCTs indicated that technology-based distance physical rehabilitation had a similar effect on ADL (standard mean difference 0.06; 95% confidence interval: −0.22 to 0.35, $P=.67$) compared to the combination of traditional treatments (usual care, similar and other treatment). Similar results were obtained for other outcomes, except inconsistent findings were noted for walking. Methodological quality of the studies and quality of evidence were considered low.

Conclusions: The findings suggest that the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning might be similar compared to traditional treatments in stroke. Further research should be performed to confirm the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning of persons with stroke.

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Stroke is one of the leading causes of death and long-term disability worldwide.[1,2] The most important risk factors for stroke have been noted diabetes, hypertension, and smoking.[3,4] Symptoms of stroke vary individually with a wide range of motoric, mental, lingual, sensory, and cognitive impairments that cause functional challenges in daily life and decrease the quality of life.[5-7] Recovery from stroke (ie, improvement of daily functional activities) is usually very individual and rapid in the acute stage of the disease, but may require several months or years of rehabilitation in some stroke survivors.[8,9] It has been estimated

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that approximately one-third stroke survivors show low functional performance at 5 years after stroke onset.[10] Therefore, rehabilitation is an important part of poststroke care and is highly needed, although substantive advances have been made in acute stroke management.[11]

In previous decades, technology-driven treatments such as virtual reality and robotics have gained popularity in stroke rehabilitation.[11-14] These systematic reviews have reported that the effectiveness of technology-driven treatments is similar to that of traditional treatments in improving the outcomes of physical functioning such as grip strength, gait speed, upper extremity functioning, or global motor functioning in persons with stroke.[11-14] To date, treatments involving virtual reality and/or robotics usually depend on facility requirements, face-to-face interaction between a patient and a health care professional, and advanced technology. Moreover, these technologies may not always be user-friendly for participants and exert a considerable economic burden on the health care system and institutes.[15,16]

Few systematic reviews have investigated the effectiveness of distance rehabilitation in persons with stroke.[17-19] Laver et al[17] examined the effectiveness of telerehabilitation consisting of 10 randomized controlled trials (RCTs) involving a total of 933 participants. Interventions focused on all types of home-based telerehabilitation using telephone, videoconferencing, desktop videophones, in-home messaging device, or combination of email, online chat programs, and virtual online library.[17] This review did not show differences in the activities of daily living (ADL), quality of life, or upper extremity functioning of persons with stroke receiving telerehabilitation and those receiving face-to-face rehabilitation or no rehabilitation. Also, Chen et al[18] compared all types of telerehabilitation with that of traditional treatments by assessing 7 RCTs and observed no substantial differences in ADL (n=792), balance (n=52), or upper extremity functioning (n=46).[18] A systematic review by Johansson et al[19] on all types of telerehabilitation in stroke care involving overall 9 RCT, observational, and qualitative studies concluded that home-based telerehabilitation or technology-based virtual rehabilitation improved the physical health of stroke survivors. However, the same systematic review indicated the need for additional studies on telerehabilitation, especially to determine its cost-effectiveness and resource utilization.[19]

To conclude, there is a call for gathering more evidence on the effectiveness of technology-based distance rehabilitation in stroke, especially focused only on physical rehabilitation interventions. The present study investigated the effectiveness of technology-based distance physical rehabilitation interventions on physical functioning compared to a combination of traditional treatments such as similar treatment, other treatment, and usual care in persons with stroke. In this review, technology-based distance physical rehabilitation interventions were defined as any physical functioning-, activity-, or exercise-promoting interventions that used a technological device that was monitored or guided by a health care professional remotely. In addition, physical functioning refers to the International Classification of Functioning, Disability and Healthy (ICF) categories of body function, activities, and participation.[20]

List of abbreviations:

ADL	**activities of daily living**
BBS	**Berg Balance Scale**
GRADE	**Grading of Recommendations, Assessment, Development and Evaluation**
ICF	**International Classification of Functioning, Disability and Health**
LLFDI	**Late-Life Function and Disability Instrument**
PICOS	**patient, intervention, comparison, outcome, study design**
RCT	**randomized controlled trial**
SIS	**Stroke Impact Scale**
SMD	**standard mean difference**

Methods

Search strategy

A systematic literature search was conducted using the following databases: Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health Literature, Excerpta Medica Database, Database of the National Library of Medicine, Physiotherapy Evidence Database, and Web of Science. The first search was performed for studies published between January 2000 and March 2017. Updated searches were conducted using the same databases for studies published between April 2017 to September 2017 and October 2017 to May 2018. A combined flow chart of study selection is presented in fig 1. Details of the protocol used for performing this systematic review are registered on Prospective Register of Systematic Reviews and can be accessed at www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42017065918.

Inclusion criteria were designed according to the patient, intervention, comparison, outcome, study design (PICOS) framework and were as follows: (P) persons with stroke; (I) any technology (eg, wearable device, Internet, telephone calls, or smartphone application) used to monitor, promote, or increase physical functioning as a distance physical rehabilitation intervention; (C) any control group not receiving rehabilitation intervention (ie, wait-list) or receiving rehabilitation intervention without the use of technology (ie, no rehabilitation, in-person physical rehabilitation interventions, or other treatment of monitoring, promoting, or increasing physical functioning); (O) outcome measures of physical functioning; and (S) RCTs that were published in English, Finnish, Swedish, or German. Literature search was limited also to research in humans. Systematic reviews, nonrandomized or noncontrolled interventional studies, observational studies, discussion or short reports, abstracts, qualitative studies, and protocols were excluded from the review. Moreover, studies involving other participants with different diagnosis without a separate analysis of persons with stroke were excluded.

A researcher (A.R.) performed the searches in the selected databases along with other members of the research team (V.P. and T.S.) and 2 information specialists. Search terms included various technology terms and interventional study types (ie, RCT or clinical trial), comprehensive keywords describing physical rehabilitation interventions (eg, exercise, exercise therapy, therapies, therapy modalities, rehabilitation, multidisciplinary therapy, motor activity, participation, physical activity), and stroke-related terms (eg, stroke, brain infarction, cerebrovascular disease). The original search strategies are described in supplemental appendix S1 (available online only at http://www.archives-pmr.org/). The search strategy used medical subject headings or keyword headings. An additional manual search was conducted using references mentioned in the retrieved studies.

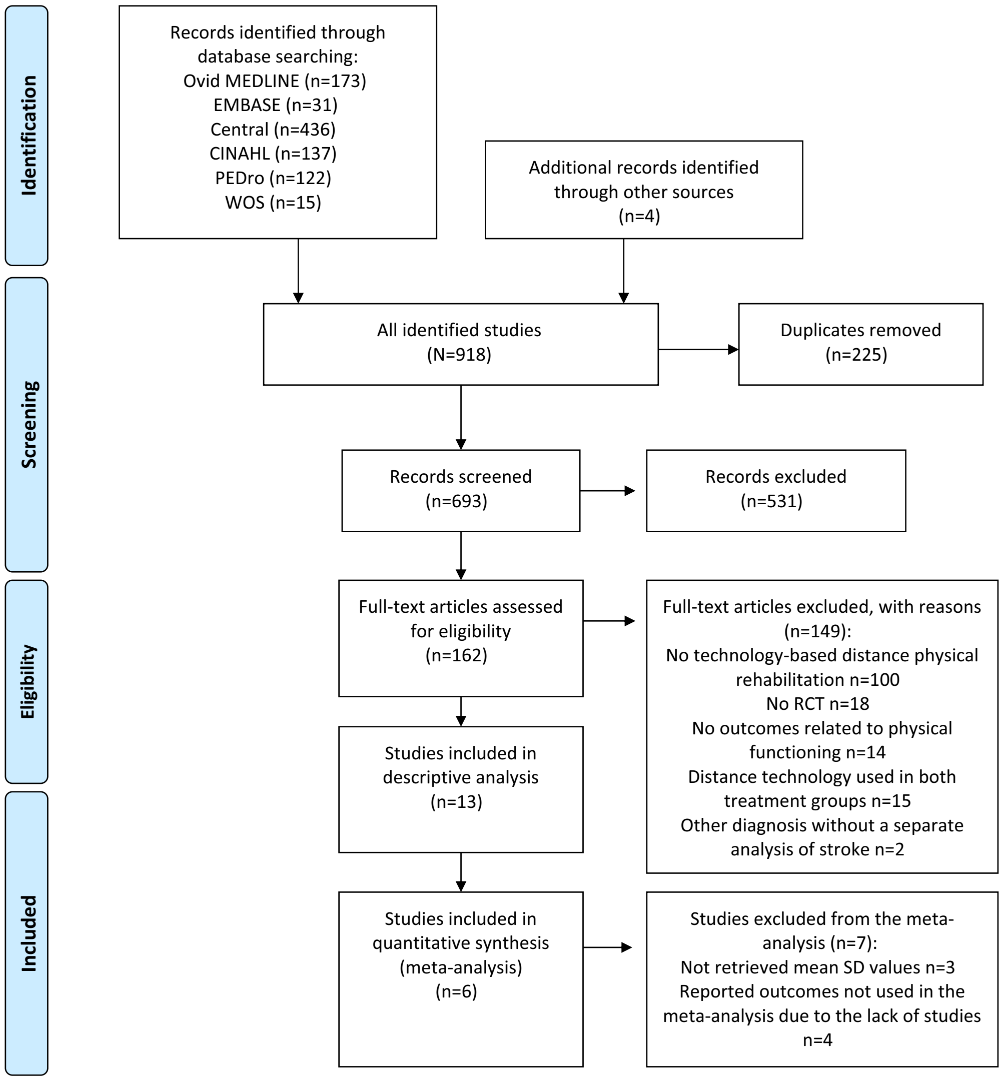

Fig 1 Flow chart of study selection. Abbreviations: CINAHL, Cumulative Index to Nursing and Allied Health Literature; EMBASE, Excerpta Medica Database; PEDro, Physiotherapy Evidence Database; WOS, Web of Science.

Data extraction

Two reviewers (A.R. and V.P.) independently screened the titles and abstracts of the studies in line with the Preferred Reporting Items for Systematic Reviews and Meta-analysis guidelines[21] using the PICOS criteria. Next, relevant studies satisfying the PICOS criteria were independently evaluated for full-text assessment by 2 reviewers (A.R. and V.P.). A third reviewer (S.H.) evaluated the studies in case of a disagreement. If needed, corresponding authors of the included studies were contacted for obtaining additional information. Agreement level between the reviewers was assessed using Cohen's kappa, with a value of 0.62 indicating substantial agreement in the title and abstract screening and 0.71 indicating substantial agreement in the full-text study screening.[22]

Methodological quality of the studies and quality of evidence

Methodological quality of the included RCTs was assessed independently by 2 reviewers (A.R. and V.P.) using the Furlan method guideline for systematic reviews.[23] A third reviewer (S.H.) was consulted in case of a disagreement. The 13-item Furlan method guideline for systematic reviews rates RCTs based on (1) adequate randomization; (2) concealment of treatment allocation; (3) blinding of participants; (4) blinding of care providers; (5) blinding of outcome assessors, (6) described and acceptable rates of dropout; (7) analysis of participants in allocated groups; (8) suggestion of selective outcome reporting; (9) similarity among groups at baseline; (10) no or similar cointervention; (11) compliance; (12) timing of outcome assessment; and (13) no other sources of potential bias.[23] An item was scored positive (*yes*) if the criterion was fulfilled, negative (*no*) if the criterion was not fulfilled, or unclear (*unsure*) if required information was inadequately reported. The total score of a study reflected the total sum of positive scores. The maximum score of a study according to the Furlan (2015) method guideline for systematic reviews was 13 points.

The quality of evidence according to the outcomes was evaluated independently by 2 reviewers (A.R. and V.P.) using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) guideline. The quality of evidence was classified as high (ie, further research is unlikely to change our confidence in the effect estimate), moderate (ie, further research is likely to have an important effect on our confidence in the effect estimate), low (ie, further research is highly likely to have an important effect on our confidence in the effect estimate), or very low (ie, any estimate of the effect is highly uncertain).[24,25] Because this review only included RCTs, evaluation was initiated from the highest quality level. Based on our independent evaluations, we downgraded the quality of evidence depending on the risk of bias, inconsistency, indirectness (eg, generalizability), imprecision (eg, insufficient data), or publication bias.[26]

Statistical synthesis

General characteristics for study and participants were extracted, and descriptive analysis was performed on all selected outcomes. Outcome measures of physical functioning were linked to the ICF categories of body function, activities, and participation by 2 researchers (A.R. and J.P.), and the ICF categories were used as a tool to capture similar outcomes into meta-analysis or descriptive analysis.[27,28] Meta-analyses were performed separately for captured outcomes of physical functioning that were similar if ≥5 studies reported meaningful data. Additional subanalyses of used technology were investigated if applicable. If adequate posttreatment values (mean and SD) were not reported in the original study, a request was sent to the corresponding author of this study. The study was excluded from the meta-analysis if no response was obtained from the corresponding author. If a study reported SE values instead of SD values, SD values were obtained from the SE values of the means by multiplying the SE values by the square root of the sample size within a group. Standard mean difference (SMD) between the experimental and control groups was calculated for each study. Mean difference was calculated if studies in the same meta-analysis used the same outcome assessment. In accordance with the Cochrane guidelines for systematic reviews and meta-analysis, values of outcome were multiplied by −1 if required so that high values reflected better physical functioning.[29] Meta-analyses were performed using a random-effects model. Pooled effect estimates for a combination of single effects of the RCTs were analyzed using Review Manager 5.3.5[a] statistical software analysis package. SMD between the groups was classified as large (>0.5), moderate (0.3-0.5), small (0.1-0.2), or insubstantial (<0.1).[30] A study was defined as having a low methodological quality if its score was ≤6 points according to the Furlan method guideline. Results of the meta-analyses are presented using forest plots of the SMD or mean difference. Statistical heterogeneity was evaluated using I^2 statistic, with a value close to 0 indicating low heterogeneity.[31] Possible publication bias was investigated using funnel plots.[32]

Results

The literature search identified 693 studies after removing duplicate studies. Screening of 162 full-text studies revealed 13 studies that fulfilled the inclusion criteria, and these studies were included in quantitative synthesis and descriptive analysis.[33-45] A flow chart of the screening process is presented in fig 1, and specific details of the included studies are shown in table 1. A table with the used technologies and the communication between the health care professional and the participant is presented in supplemental appendix S2 (available online only at http://www.archives-pmr.org/).

Description of study participants

Selected studies included 605 stroke survivors, of which 304 were included in the experimental group and 301 were included in the control group (see table 1). The mean age ± SD of the study participants was 65.2±4.2 years. Ten out of 13 studies reported an average disease duration since diagnosis of 10.6±11.2 months (range, ≤1mo-36mo). Of the 605 study participants, 65% were men and 87% had experienced ischemic stroke. Four studies did not report the stroke type.[33,36,38,43] Only 6 studies reported the affected side of hemiparesis, with most of the participants (53%) showing left hemiparesis.[33,34,37,39-41] Inclusion criteria of impairment and disability levels due to a stroke were defined across the included studies with measurements of independent walking,[33,39] ADL,[35,36,44,45] or upper extremity functioning.[34,37,38,40,41,43] One study did not report impairment and disability levels as inclusion criteria,[42] and 11 out of 13 studies used cognitive impairment or psychiatric illness as an exclusion criterion.[33-39,41,42,44,45]

Description of technology-based distance physical rehabilitation interventions

The most common technology used for providing distance physical rehabilitation interventions was online video monitoring, which was used in 5 of 13 studies.[35,36,38,41,44] Therapists used online video techniques for monitoring physical home exercises, goal settings, or overall treatment.[35,36,38,41,44] However, the frequency of this technology in the interventions was heterogeneous, ranging from 3[36,38] to 5[41,44] times per week, and 1 study did not report the frequency of online video monitoring.[35] Three of these 5 studies used other technologies alongside online video monitoring, such as telephone calls and messaging,[36] gamification,[38] or accelerometer.[44] The second most common technology used for providing distance physical rehabilitation interventions was telephone calls conducted by a therapist or a nurse, which was used in 3 of 13 studies.[33,39,45] The frequency of telephone calls varied from only 3 telephone calls in a 6-month study period to 1 telephone call in a 4-week study period.[33,39,45] The remaining 5 studies used technologies such as exercise videos through an electronic tablet,[37] virtual training program for upper extremity functioning,[34,43] exercises from a digital video disc,[42] or combination of physical exercise programs through the Internet along with gamification.[40]

Eight studies reported that health care professionals and participants interacted in real time through an online video or through telephone calls.[18,33,36,38,39,41,44,45] Only 1 of 13 studies used 1-way communication where the therapist monitored physical exercise and provided feedback to participants if necessary through the Internet without any real-time communication.[40] Four of 13 studies did not involve any direct communication or self-monitoring options, because they used a virtual training program without any feedback or exercise videos through an electronic tablet or a digital video disc.[34,37,42,43]

Content of interventions in the experimental group

Mean ± SD duration of the interventions was 9.2±6.0 weeks. The content of the intervention in the experimental group was very heterogeneous (see table 1). Four of 13 interventions focused on overall and individualized physical exercises for improving mobility, strength, balance, walking, and stretching.[35-37,42] Five

Table 1 Summary of RCTs on technology-based distance physical rehabilitation interventions with outcomes related to physical functioning compared to similar or other treatment, and usual care without the use of technology in stroke

Study, Country	Duration	n (% Men)	Experimental n (% Men)	Control n (% Men)	Age (y) Experimental/ Control	Participants	Intervention in the Experimental Group	Intervention in the Control Group	Outcomes
Ada et al,[33,*] Australia	4 wk, FU 12 wk	27 (70)	13 (69)	14 (71)	66/66	Persons with stroke from general community	Clinic-based treadmill and overground walking 3 × week for 45 min supervised by a physiotherapist	Home-based exercise program for lower limb muscles, balance, and coordination Telephone calls once a week with a physiotherapist (total 4 ×)	10-m walking test
Ballester et al,[34] Spain	3 wk, FU 12 wk	35 (40)	17 (47)	18 (33)	65/62	Outpatients with stroke from a clinical hospital	Home-based nonsupervised AEMF-virtual training program for the assessment of upper-limb motor functioning. Training comprised 3 tasks: hit, grasp, and place, with a total duration of 20 min per training. Occupational therapists did not give any explicit feedback about the performance during the intervention.	Usual care of home-based nonsupervised upper extremity functioning tasks without the technology	Fugl-Meyer Assessment Barthel Index
Chen et al,[35] China	12 wk, FU 12 wk	54 (61)	27 (67)	27 (56)	66/66	Persons with stroke as outpatients	Home-based telesupervising rehabilitation including physical exercises and ETNS. Physical exercises included stretching, motor imagery therapy, balance exercises, and walking exercises for 1 h twice a day (total 60 sessions) with ETNS for 20 min twice a day for 12 wk (total 60 sessions). Therapists supervised the participants to do the physical exercises and ETNS by live video conferencing.	Similar physical exercises and ETNS program without telesupervising	Modified Barthel Index BBS

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Table 1 (*continued*)

Study, Country	Duration	n (% Men)	Experimental n (% Men)	Control n (% Men)	Age (y) Experimental/ Control	Participants	Intervention in the Experimental Group	Intervention in the Control Group	Outcomes
Chumbler et al,[36] the United States	12 wk, FU 12 wk	48 (98)	25 (96)	23 (100)	67/68	Persons with stroke from Veterans Affairs facility center	Multifaceted stroke telerehabilitation intervention to improve functional mobility including individual strength and balance exercises, goal settings, and treatment plan 3 home video televisits remotely with a teletherapist (physical or occupational therapist) with the help of an assistant at home, 5 telephone calls, and in-home messaging device between patients and teletherapists	Usual care	FONEFIM LLFDI
Emmerson et al,[37] Australia	4 wk, no FU	62 (63)	30 (61)	32 (63)	68/63	Persons with stroke from general community	Home exercise program as video format on an electronic tablet (iPad) with automated reminders Home exercise program consisted of exercises of stretching, range of movement, strength, and fine motor and coordination for 1-2 × per day designed by occupational therapists who updated the videos throughout the program. All participants completed their usual individual and/or group therapy throughout the intervention.	Similar home exercise program without technology (paper based). All participants completed their usual individual and/or group therapy throughout the intervention.	Wolf Motor Function Test

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Table 1 (*continued*)

Study, Country	Duration	n (% Men)	Experimental n (% Men)	Control n (% Men)	Age (y) Experimental/ Control	Participants	Intervention in the Experimental Group	Intervention in the Control Group	Outcomes
Lin et al,[38] Taiwan	4 wk, no FU	24 (71)	12 (83)	12 (58)	75/76	Persons with stroke living in long-term care facilities	An online web-based telerehabilitation program monitoring the change of body position, standing exercises, environment, and the use of upper extremities including animated videos and interactive gaming. The physiotherapist could monitor the sequences and durations with light to moderate exercise intensity (Borg scale 12-14). 3 × per week for 50 min for each session, online video monitoring.	Usual care	BBS Barthel Index
Moore et al,[39,*] United Kingdom	19 wk, no FU	40 (85)	20 (90)	20 (80)	68/70	Persons with stroke from a general community	Supervised leisure center classes run by a physiotherapist and physical activity instructor for 3 × per week for 45-60 min. Exercises were targeted to increase functional movement (strength, balance, cardiovascular).	Matched-duration home stretching program with instructions for using a booklet and diary to record stretches and changes in medication, diet, and physical activity. Telephone calls every 2 wk (total 10 ×).	10-m walking test BBS SIS
Nijenhuis et al,[40] The Netherlands	6 wk, FU 8 wk	19 (53)	9 (78)	10 (30)	58/62	Persons with chronic stroke from rehabilitation center and regional hospitals	Self-administered home-based arm and hand training for 6 × per week for 30 min, using either a passive dynamic wrist or a hand orthosis combined with computerized gaming exercises designed by a therapist. Therapists monitored progress without real-time supervision and adjusted training programs remotely via a website.	Prescribed conventional exercises from an exercise book	Fugl-Meyer Assessment SIS

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Table 1 (*continued*)

Study, Country	Duration	n (% Men)	Experimental n (% Men)	Control n (% Men)	Age (y) Experimental/ Control	Participants	Intervention in the Experimental Group	Intervention in the Control Group	Outcomes
Piron et al,[41] Italy	4 wk, FU 4 wk	36 (58)	18 (61)	18 (56)	66/64	Persons with stroke as outpatients	Home-based telerehabilitation program consisting of a virtual environment where a patient conducted motor tasks for upper extremities, coupled with a videoconference tool provided by a physiotherapist for 5 times per week for 60 min. Therapist provided real-time feedback to the patient through the videoconferencing system.	Usual care	Fugl-Meyer Assessment
Redzuan et al,[42] Malaysia	12 wk, no FU	90 (58)	44 (40)	46 (60)	64/59	Persons with subacute stroke	Home-based audiovisual DVD including 45-min self-instructional therapy with 6 sections: (1) positioning and handling; (2) bed mobility; (3-4) movement, stretching, and strengthening exercises for lower and upper limbs; (5) transfer techniques; and (6) ADL. Content of the DVD was reviewed by physiotherapists, an occupational therapist, and a rehabilitation physician. Additional therapy twice-monthly.	Usual care for weekly therapy (1h/wk)	Modified Barthel Index
Standen et al,[43] United Kingdom	8 wk, no FU	27 (64)	17 (47)	10 (80)	59/63	Stroke patients	Home-based virtual reality training employing infrared capture to translate the position of the hand into game play (Nintendo Wii) for 20 min/3 × per day	Usual care	Nottingham Extended Activities of Daily Living Scale Wolf Motor Function Test

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Table 1 (*continued*)

Study, Country	Duration	n (% Men)	Experimental n (% Men)	Control n (% Men)	Age (y) Experimental/ Control	Participants	Intervention in the Experimental Group	Intervention in the Control Group	Outcomes
van den Berg et al,[44] The Netherlands	8 wk, FU 4 wk	63 (64)	31 (66)	32 (61)	65/70	Stroke patients and their caregivers	Telerehabilitation comprised a caregiver-mediated training program with a support of a customized exercise application loaded into a tablet. Exercises for the patients included gait and gait-related mobility such as standing, turning, or making transfers for 5 times per week for 30 min. Telerehabilitation was conducted via the exercise application and videoconferencing to provide access to the treating physiotherapist. Therapists also had weekly home visits. Patients also wore an activity monitor (the Fitbit Zip) to increase physical activity through real-time feedback.	Usual care	10-m walking test SIS BBS Barthel Index Fugl-Meyer Assessment
Wan et al,[45] China	24 wk, no FU	80 (71)	40 (75)	40 (68)	59/60	Persons with stroke as outpatients	Nurse-lead telephone call intervention for secondary prevention of ischemic stroke 3 telephone FU calls at wk 1 and at mo 1 and 3 after discharge (for 15-20min) to promote self-management techniques and maintenance of behavioral improvements Physical activity guideline of moderate to intense exercise 3-5 days per week for 30 min.	Usual stroke education for secondary prevention	The Health Promoting Lifestyle Profile II Modified Rankin Scale

Abbreviations: AEMF, automated evaluation of motor function; DVD, digital video disc; ENTS, electromyography-triggered neuromuscular stimulation; FU, follow-up.
* In this study, control group used technology-based distance physical rehabilitation intervention and was treated as the reference group.

of 13 interventions included only upper extremity exercises performed in a virtual environment at home,[34,41,43] balance and body position exercises,[38] or use of orthoses.[40] Two of 13 interventions focused on lower extremity exercises such as gait-related exercises with balance and coordination exercises.[33,44] Finally, 2 of 13 interventions focused on increasing and promoting physical activity.[39,45] Twelve of 13 interventions were monitored or programmed by a physiotherapist or an occupational therapist, or by both.[33-44] Only 1 intervention was a nurse-led stroke prevention program for improving physical activity.[45]

Effectiveness of technology-based distance physical rehabilitation interventions

Seven outcomes of physical functioning were identified from the selected studies (tables 1 and 2). These outcomes were ADL, upper extremity functioning, lower extremity functioning, balance, walking, physical activity, and participation. Descriptive analysis was performed on all the outcomes and meta-analysis was only conducted from ADL, because for other outcomes there were not enough data to perform meaningful meta-analyses. Meta-regression analyses were not performed because of a lack of studies.

Activities of Daily Living

Nine studies investigated ADL of participants receiving technology-based distance physical rehabilitation interventions.[34-36,38,39,42-45] ADL was measured using 6 ADL instruments, namely, the Barthel Index,[34,38,44] Modified Barthel Index,[35,42] Modified Rankin Scale,[45] telephone version of the FIM,[36] ADL domain of Stroke Impact Scale (SIS),[39] and the Nottingham Extended ADL Scale.[43] ADL instruments were identified for mobility (d4), self-care (d5), and domestic life (d6) in ICF categories of activities and participation.

A meta-analysis was performed from 6 studies for ADL outcome.[35,36,38,39,42,45] Technology-based distance physical rehabilitation interventions had a similar effect on ADL when compared to control group with the combination of similar treatment, other treatment, and usual care (SMD 0.06; 95% confidence interval: −0.22 to 0.35, $P=.67$) (fig 2). Technologies and the content of the interventions in the experimental group were heterogeneous, with most often used technology being online video monitoring to enable physical exercises.[35,36,38] The overall results of the meta-analysis indicated that the included studies were moderately heterogeneous ($I^2=38\%$). Subanalysis of different technologies did not show differences between the groups, but within 1 technology group there was no heterogeneity observed (see fig 2) Funnel plot did not indicate any publication bias (supplemental appendix S3, available online only at http://www.archives-pmr.org/). Descriptive analysis from all studies indicated similar findings as in the meta-analysis regardless of the used technology or comparison group (see table 2).

Upper extremity functioning

Six studies investigated upper extremity functioning of participants receiving technology-based distance physical rehabilitation interventions through online video monitoring[36,41] exercise videos,[37] virtual reality training or its combination with gamification (ie, any game-design elements improving physical functioning)[34,43] or the combination of monitoring through Internet and gamification[40] (see table 1). Outcomes of upper extremity functioning were determined using the Late-Life Function and Disability Instrument (LLFDI),[36] the Fugl-Meyer Assessment,[34,40,41] or the Wolf Motor Function Test.[37,43] Outcomes of upper extremity functioning were interpreted for neuromusculoskeletal- and movement-related functions (b7) in the ICF category of body function or for mobility (d4) in the ICF categories of activities and participation, depending on whether the instrument focused only on motor function or on functional capacity. Descriptive analysis revealed similar effects between technology-based distance physical rehabilitation interventions and control groups with combination of usual care[34,36,40,41,43] or similar treatment without the use of technology[37] (see table 2).

Lower extremity functioning

Only 2 studies investigated lower extremity functioning using lower extremity domains of LLFDI[36] or Fugl-Meyer Assessment.[44] Both studies instructed physical exercises such as balance and gait-related physical exercises through telerehabilitation (see table 1). Similar as in upper extremity functioning, instruments assessing lower extremity functioning were interpreted for neuromusculoskeletal- and movement-related functions (b7) in the ICF category of body function and for mobility (d4) in the ICF categories of activities and participation. Descriptive analysis indicated that technology-based distance physical rehabilitation enabled through telerehabilitation had the similar effect on lower extremity functioning when compared with usual care (see table 2).[36,44]

Balance

Balance was assessed in 4 technology-based distance physical rehabilitation interventions that were enabled through online video monitoring[35,38,44] or telephone calls.[39] All of these 4 studies used the Berg Balance Scale (BBS) as an outcome for balance,[35,38,39,44] but only 3 of them reported BBS values. BBS was linked to the domain of mobility (d4) in the ICF categories of activities and participation. Descriptive analysis showed that technology-based distance physical rehabilitation interventions had a similar effect on balance when compared to control group with the combination of usual care, similar or other treatment (see table 2).

Walking

Outcomes of walking was assessed in 3 studies that compared telephone-enabled distance physical rehabilitation interventions with other treatments (see table 2). Walking tests were performed using a 10-m walking test.[33,39,44] Walking was linked to the domain of mobility (d4) in the ICF categories of activities and participation. Descriptive analysis showed that 2 of these 3 studies had a better improvement on walking ability for participants in the control group receiving either supervised clinic-based treadmill training[33] or leisure-center exercise training[39] compared to technology-based distance physical rehabilitation interventions offering home-based exercises that were monitored through telephone calls. However, Van den Berg et al[44] study found similar effect between groups when distance physical rehabilitation interventions enabled by home-based physical exercises through online video monitoring and smartphone application were compared with usual care (see table 2).

Physical activity

Only 2 studies investigated physical activity on the effectiveness of technology-based physical rehabilitation interventions to either

Table 2 Results of outcome variables concerning technology-based distance physical rehabilitation interventions on physical functioning in stroke

Study and Outcome	Experimental			Control			Group Differences at Endpoint (Effect/ Effect Size)	Group Differences at Endpoint *P* Value (95% CI)
	n	M1 Mean ± SD	M2 Mean ± SD	n	M1 Mean ± SD	M2 Mean ± SD		
ADL								
Ballester et al[34]	17			18				
Barthel Index (0-100)		89.5±9.4	Not rep.		84.7±14.2	Not rep.	ES= −0.41	.44
Chen et al[35]	27			27				
Modified Barthel Index (0-100)		55.6±12.8	61.4±12.9		54.3±13.4	59.8±12.3	F=0.11	.90*
Chumbler et al[36]	22			22				
FONEFIM (18-126)		83.5±9.5	82.7±9.7		81.5±12.1	79.0±15.0	-	.31*
Lin et al[38]	12			12				
Barthel Index (0-100)		52.9±32.9	57.9±3.1		57.9±26.7	60.8±22.5	-	.45†
Moore et al[39,‡]	20			20				
SIS, ADL (0-100)		82.0±19.0	85.0±25.0		90.0±17.0	90.0±15.0	-	.39* (−3.0 to 8.0)
Redzuan et al[42]	44			46				
Modified Barthel Index (0-100)		46.7±22.3	78.8±20.2		61.3±24.3	86.6±16.3	-	Not rep.
Standen et al.[43]	9			9				
Nottingham Extended Activities of Daily Living		Not rep.	Not rep.		Not rep.	Not rep.	ES = 1.06	>.05
van den Berg et al[44]	31			32				
Barthel Index (0-100)		Not rep.	Not rep.		Not rep.	Not rep.	-	.38
Wan et al[45]	40			40				
Modified Rankin Scale (0-3)		0.60±1.0	0.18±0.5		0.70±1.1	0.40±0.7	F=0.52	.56*
UE functioning								
Ballester et al[34]	17			18				
Fugl-Meyer Assessment, UE (0-66)		42.9±14.4	Not rep.		43.4±13.5	Not rep.	ES= −0.30	.33
Chumbler et al[36]	22			22				
LLFDI, UE (0-100)		64.7±21.2	70.1±19.4		65.6±17.2	64.1±17.8	-	.43*
Emmerson et al[37]	28			30				
Wolf Motor Function Test (s)		39.0±44.0	33.0±37.0		49.0±47.0	45.0±44.0	-	.10 (−11.0 to 1.0)
Nijenhuis et al[40]	9			10				
Fugl-Meyer Assessment, UE (0-66)		33.0±20.1	34.2±19.9		32.9±14.9	34.9±15.7	-	>.05
Piron et al[41]	18			18				
Fugl-Meyer Assessment, UE (0-66)		48.5±7.8	53.6±7.7		47.3±4.6	49.5±4.8	-	Not rep.
Standen et al[43]	9			9				
Wolf Motor Function Test (s)		Not rep.	Not rep.		Not rep.	Not rep.	-	Not rep.
LE functioning								
Chumbler et al[36]	22			22				
LLFDI, advanced LE (0-100)		32.5±19.0	40.7±20.6		37.9±17.4	35.2±17.8	-	.20*
van den Berg et al[44]	31			32				
Fugl-Meyer Assessment, LE (0-66)		Not rep.	Not rep.		Not rep.	Not rep.	-	.07

(*continued on next page*)

Table 2 (*continued*)

Study and Outcome	Experimental n	Experimental M1 Mean ± SD	Experimental M2 Mean ± SD	Control n	Control M1 Mean ± SD	Control M2 Mean ± SD	Group Differences at Endpoint (Effect/ Effect Size)	Group Differences at Endpoint *P* Value (95% CI)
Balance								
Chen et al[35]	27			27				
BBS (0-56)		33.1±4.0	37.0±3.8		31.7±5.9	36.1±5.3	F=1.42	.91*
Lin et al[38]	12			12				
BBS (0-56)		20.4±17.0	24.6±18.4		22.4±18.4	26.9±18.0	-	.83†
Moore et al[39,‡]	20			20				
BBS (0-56)		50.0±4.0	55.0±2.0		50.0±5.6	52.0±5.0	-	<.01* (0.9 to 5.0)
Van den Berg et al[44]	31			32				
BBS (0-54)		Not rep.	Not rep.		Not rep.	Not rep.	-	
Walking								
Ada et al[33,‡]	11			14				
10-m walking test (m/s)		0.62±0.24	0.75±0.26		0.53±0.30	0.56±0.30	F=6.53	.02
Moore et al[39,‡]	20			20				
10-m walking test (m/s)		1.2±0.4	1.5±0.3		1.2±0.3	1.3±0.3	-	<.01* (0.1 to 0.3)
van den Berg et al[44]	31			32				
10-m walking test (m/s)		Not rep.	Not rep.		Not rep.	Not rep.	-	.87
Physical activity								
Moore et al[39,‡]	20			20				
SIS-16, physical total (0-400)		308.0±92.0	324.0±96.0		336.0±78.0	348.0±64.0	-	.67* (−15.0 to 24.0)
Wan et al[45]	40			40				
Health Promoting Lifestyle Profile II, physical activity (1-4)		1.7±0.7	2.3±0.7		1.8±0.7	2.2±0.7	F=0.54	.47*
Participation								
Chumbler et al[36]	22			22				
LLFDI, overall function (0-100)		49.5±10.1	54.6±13.6		51.7±12.8	49.6±12.0	-	.25*
Moore et al[39,‡]	20			20				
SIS, participation (0-100)		72.0±29.0	76.0±28.0		89.0±18.0	89.0±18.0	-	.31* (−7.0 to 21.0)
Nijenhuis et al[40]	9			10				
SIS, participation (0-100)		57.3±13.0	58.9±11.5		66.7±16.0	67.9±14.6	-	>.05
van den Berg et al[44]	31			32				
SIS, participation (0-100)		Not rep.	Not rep.		Not rep.	Not rep.	-	.49

NOTE. Not rep.: study did not report the values.
Abbreviations: 95% CI, 95% confidence interval; FONEFIM, telephone version of the FIM; LE, lower extremity; M1, baseline value; M2, post intervention endpoint value; UE, upper extremity.
* Group × time effect.
† Training × group effect.
‡ Control group was treated as experimental group due to using technology-based distance physical rehabilitation intervention.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
3.1.1 Online video monitoring or combination with other technology									
Chen et al[35]; MBI (0-100)	61.4	12.9	27	59.8	12.3	27	17.2%	0.13 (-0.41 to 0.66)	2017
Lin et al[38]; BI (0-100)	57.9	3.1	12	60.8	22.5	12	9.7%	-0.17 (-0.98 to 0.63)	2014
Chumbler et al[36]; FONEFIM (13-91)	82.7	9.7	22	79	15	22	15.0%	0.29 (-0.31 to 0.88)	2012
Subtotal (95% CI)			**61**			**61**	**42.0%**	**0.12 (-0.23 to 0.48)**	
Heterogeneity: Tau²=0.00; Chi²= 0.82, *df*=2 (*P*=.66); *I*²=0%									
Test for overall effect: Z=0.69 (*P*=.49)									
3.1.2 Only telephone contacts									
Wan et al[45]; MRS (0-5)	-0.18	0.5	40	-0.4	0.7	40	21.3%	0.36 (-0.08 to 0.80)	2016
Moore et al[39]; SIS/ ADL (0-100)	90	15	20	85	25	20	14.1%	0.24 (-0.38 to 0.86)	2015
Subtotal (95% CI)			**60**			**60**	**35.5%**	**0.32 (-0.04 to 0.68)**	
Heterogeneity: Tau²=0.00; Chi²=0.10, *df*=1 (*P*=.76); *I*²=0%									
Test for overall effect: Z=1.73 (*P*=.08)									
3.1.3 DVD exercises									
Redzuan et al[42]; MBI (0-100)	78.8	20.2	44	86.6	16.3	46	22.6%	-0.42 (-0.84 to -0.00)	2012
Subtotal (95% CI)			**44**			**46**	**22.6%**	**-0.42 (-0.84 to -0.00)**	
Heterogeneity: Not applicable									
Test for overall effect: Z=1.98 (*P*=.05)									
Total (95% CI)			**165**			**167**	**100.0%**	**0.06 (-0.22 to 0.35)**	
Heterogeneity: Tau²=0.05; Chi²=8.11, *df*=5 (*P*=.15); *I*²=38%									
Test for overall effect: Z=0.43 (*P*=.67)									
Test for subgroup differences: Chi²=7.19, *df*=2 (*P*=.03), *I*²=72.2%									

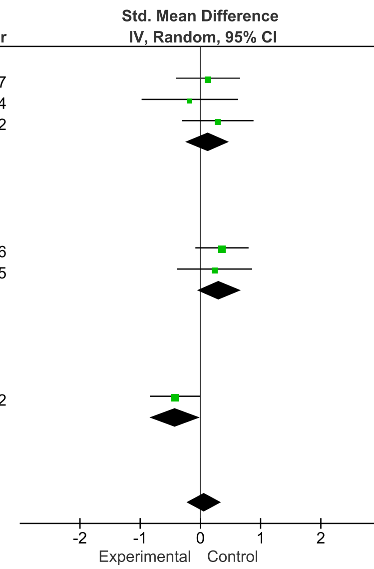

Fig 2 Meta-analysis and additional sensitivity analysis on ADL compared to control group of similar or other treatment, and usual care without the use of technology. The squares and diamonds represent the test values for individual studies and overall effectiveness; SMD with 95% CI. Abbreviations: 95% CI, 95% confidence interval; FONEFIM, the telephone version of FIM; MBI, Modified Barthel Index; MRS, Modified Rankin Scale.

other treatments[39] or physical activity health promotion for nurse-led secondary prevention of ischemic stroke.[45] Physical activity was investigated using the physical activity subscales in SIS[39] and Health Promoting Lifestyle Profile II.[45] We identified physical activity in the domain of self-care (d5) in the ICF categories of activities and participation. Both studies showed similar effects between the groups with respect to the outcomes of physical activity when compared to usual care and other treatments (see table 2).[39,45]

Participation

Four studies investigated participation in technology-based physical rehabilitation interventions enabled through telephone calls (3 studies) and website exercises (1 study) compared to usual care[36,40,44] or other treatment.[39] Studies captured the outcome of participation with either the SIS[39,40,44] or LLFDI.[36] The instruments of participation were identified for mobility (d4), self-care (d5), and domestic life (d6) in ICF categories of activities and participation (see table 2). All studies indicated similar effect on participation between the experimental group compared and usual care[36,40,44] or other treatment (ie, supervised leisure-center exercise classes for people with stroke).[39]

Methodological quality and quality of evidence

The overall methodological quality of the studies was low (median: 6, interquartile range: 6-9) according to the Furlan method guideline (table 3).[23] The methodological quality was high (>9/13) in 4 studies,[33,37,39,44] moderate (7-8/13) in 2 studies,[35,36] and low (≤6/13) in 7 studies.[34,38,40-43,45] All studies used an adequate randomization method. However, only 38% studies reported an adequate treatment allocation procedure. Other main methodological faults were observed in the blinding of participants and care providers, reporting of information on selective outcomes, and compliance to the intervention. Moreover, only 3 studies used intention-to-treat analysis.[36,38,44]

GRADE evaluation was performed using the results of the meta-analysis and descriptive analyses (table 4).[26] All the outcomes indicated very low quality of evidence. For ADL, downgrading 3 levels were based on the methodological quality of the studies (risk of bias), clinical heterogeneity (inconsistency), and low number of participants included in the meta-analysis (imprecision). Similar observations were obtained for other outcomes, but only based on descriptive analysis, because meta-analyses were not able to perform due to lack of meaningful data.

Discussion

This systematic review investigated the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning in persons with stroke. Results indicated that technology-based distance physical rehabilitation interventions had a similar effect on physical functioning outcomes of ADL, upper and lower extremity functioning, balance, physical activity, and participation, when compared to the combinations of traditional treatments not involving the use of technology (ie, similar treatment, other treatment, usual care). Our findings are consistent with previous systematic reviews that assessed the effectiveness of telerehabilitation in persons with stroke, which reported no significant difference in the improvement of physical functioning between participants receiving telerehabilitation and those receiving traditional treatments.[17-19] However, our study focused only on physical rehabilitation interventions with no technology allowed in the comparison group.

Our meta-analysis involving 6 studies and 322 stroke survivors showed similar effect of technology-based distance physical rehabilitation interventions on ADL compared to the combination of similar treatment, other treatment, and usual care. ADL improved in both groups irrespective of the intervention or used technology, which was consistent with previous systematic reviews that investigated all types of telerehabilitation interventions

Table 3 Methodological quality assessment of included RCTs concerning technology-based distance physical rehabilitation interventions on physical functioning in stroke

Study	1: Randomization Method Adequate	2: Treatment Allocation Concealed	3: Blinding of Participants	4: Blinding of Care Provider	5: Blinding of Outcome Assessor	6: Dropouts Described and Acceptable	7: Participants Analyzed in the Allocated Groups	8: Free of Suggestion of Selective Outcome Reporting	9: Group Similarity at the Baseline	10: Co-intervention Avoided or Similar	11: Compliance	12: Similar Timing of the Outcome Assessment	13: Other Sources of Potential Bias Unlikely	Number of *Yes* Scores (Maximum of 13)*
Ada et al[33]	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	?	Yes	Yes	Yes	9
Ballester et al[34]	Yes	?	No	?	?	?	No	?	Yes	?	Yes	Yes	?	4
Chen et al[35]	Yes	No	No	No	Yes	Yes	Yes	?	Yes	Yes	?	Yes	Yes	8
Chumbler et al[36]	Yes	?	No	?	Yes	Yes	Yes	Yes	Yes	No	?	Yes	Yes	8
Emmerson et al[37]	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	No	Yes	Yes	Yes	9
Lin et al[38]	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	?	Yes	6
Moore et al[39]	Yes	Yes	No	?	Yes	Yes	Yes	?	Yes	?	Yes	Yes	Yes	9
Nijenhuis et al[40]	Yes	?	No	No	No	Yes	Yes	?	No	No	?	Yes	Yes	5
Piron et al[41]	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	Yes	?	6
Redzuan et al[42]	Yes	No	No	No	No	Yes	No	?	No	No	?	Yes	Yes	4
Standen et al[43]	Yes	Yes	No	?	Yes	No	No	?	?	No	?	Yes	Yes	5
van den Berg et al[44]	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	9
Wan et al[45]	Yes	?	No	?	Yes	Yes	Yes	?	Yes	No	?	Yes	?	6

* The methodological quality of the studies was assessed with Furlan method guideline[25] including 13 items (1-13) rated as positive (*yes*), negative (*no*), or not fulfilled or unsure (*?*).

Table 4 Quality of evidence in technology-based distance physical rehabilitation interventions on physical functioning in stroke

Technology-based Distance Physical Rehabilitation

Patient or population: persons with stroke receiving distance physical rehabilitation
Settings: home or rehabilitation care facilities without the present of a health care professional
Intervention: technology-based distance physical rehabilitation

Outcomes and No. of Studies	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Quality of the Evidence (GRADE)*	Comments
ADL 9 studies	Study quality by Furlan et al[23] 8/13 (moderate). Sufficient information on treatment allocation procedure only in 2 studies. Only 2 studies used ITT analysis.	Analysis consisted of subjective and objective ADL measures. ADL measures varied (BI, FONEFIM, MBI, MRS, SIS or ADL, NEADL scale). Technology varied between DVD, video monitoring, virtual training with gamification, or telephone calls. Control group was heterogeneous with usual care, similar, or treatment. Moderate statistical heterogeneity ($I^2=38\%$).	Stroke survivors with age range of 63-75. Mild to moderate physical disability without cognitive deficits	Meta-analysis of 6 studies with sample size ranging of 24-88 participants (N=332) indicated no differences. Descriptive analysis indicated no differences.	No publication bias observed in meta-analysis (supplemental appendix S2)	⊕OOO	Methodological quality indicated somewhat risk of bias. Clinical heterogeneity observed in the use of technology and in the treatments in control group. Sample size<400. Only focusing on more elderly persons with stroke with mild impairments without cognitive deficits.
Balance (BBS) 4 studies	Study quality by Furlan et al[23] 8/13 (moderate). Sufficient information on treatment allocation procedure only in 1 study. Only 1 study used ITT analysis.	Analysis consisted only BBS outcome. Technology varied between video monitoring and telephone calls. Control group was heterogeneous with usual care, similar or other treatment.	Stroke survivors with age range of 63-75. Mild to moderate physical disability without cognitive deficits	Sample size ranged from 24 to 54 participants. Descriptive analysis indicated no differences.	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias. Clinical heterogeneity observed in the use of technology and in the treatments in control group. Subanalysis to assess clinical heterogeneity was not able to perform due to the lack of studies. Sample size<400. Only focusing on more elderly persons with stroke with mild impairments without cognitive deficits.

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Table 4 (*continued*)

Technology-based Distance Physical Rehabilitation							
Patient or population: persons with stroke receiving distance physical rehabilitation Settings: home or rehabilitation care facilities without the present of a health care professional Intervention: technology-based distance physical rehabilitation							
Outcomes and No. of Studies	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Quality of the Evidence (GRADE)*	Comments
Upper extremity functioning 6 studies	Study quality by Furlan et al[23] 7/13 (moderate). Treatment allocation procedure reported sufficiently only in 1 study. Only 1 study used ITT analysis.	Analysis consisted of objective measures. Technology varied from virtual training with gamification, video online monitoring, video online monitoring combined with gamification, or video exercises without monitoring. Control group was heterogeneous with similar treatment or usual care.	Stroke survivors with age range of 60-75 Mild to moderate physical impairments without cognitive deficits	Sample size ranged from 19 to 58 participants. Descriptive analysis indicated no differences.	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias. Clinical heterogeneity observed in the use of technology and in the treatments in the control group. Subanalysis to assess clinical heterogeneity was not able to perform due to the lack of studies. Sample size<400. Only focusing on more elderly persons with stroke with mild impairments without cognitive deficits.
Lower extremity functioning 2 studies	Quality of the study by Furlan et al[23] 9/13 (high) Treatment allocation procedure reported sufficiently only in 1 study	Analysis consisted of objective measures. Technology varied from virtual training with gamification, video online monitoring, video online monitoring combined with gamification, or video exercises without monitoring. Control group consisted of usual care.	Stroke survivors with age of 67 y Mild to moderate physical impairments without cognitive deficits	Sample size N=48 N=63 Not enough reported values to conduct meta-analysis. Descriptive analysis indicated no differences.	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias. Clinical heterogeneity observed in the use of technology. Sample size in total<400. Only focusing on elderly persons with stroke with mild impairments without cognitive deficits.

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Table 4 (*continued*)

Technology-based Distance Physical Rehabilitation

Patient or population: persons with stroke receiving distance physical rehabilitation
Settings: home or rehabilitation care facilities without the present of a health care professional
Intervention: technology-based distance physical rehabilitation

Outcomes and No. of Studies	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Quality of the Evidence (GRADE)*	Comments
Walking 3 studies	Quality of the study by Furlan et al[23] 9/13 (high) Treatment allocation procedure reported sufficiently in all studies	Analysis consisted of objective measures. Technology used in the experimental groups was only telephone calls. Control group consisted of usual care (1 study) or other treatments (2 studies).	Stroke survivors with age of 60 and 69 y Mild to moderate physical impairments without cognitive deficits	Sample size N=40 N=80 Not enough reported values to conduct meta-analysis. Descriptive analysis indicated no differences.	-	⊕OOO	Clinical heterogeneity observed in the compared treatments of control groups Sample size in total<400 Only focusing on elderly persons with stroke with mild impairments without cognitive deficits
Physical activity 2 studies	Quality of the study by Furlan et al[23] 8/13 (moderate) Treatment allocation procedure reported sufficiently only in 1 study	Analysis consisted of subjective measures. Technology used in the experimental groups was only telephone calls. Control group consisted of usual care (1 study) or other treatments (1 study).	Stroke survivors with age between 63 and 69 y Mild to moderate physical impairments without cognitive deficits	Not enough studies to conduct meta-analysis	-	⊕OOO	Clinical heterogeneity observed in the compared treatments of control groups Sample size in total<400 Only focusing on elderly persons with stroke with mild impairments without cognitive deficits
Participation 4 studies	Quality of the study by Furlan et al[23] 8/13 (moderate) Treatment allocation procedure reported sufficiently only in 2 studies	Self-reported questionnaires Technology varied from telephone calls (3 studies) and website exercises (1 study). Control group consisted of traditional treatments (3 studies) and other treatment (1 study).	Stroke survivors with age between 60 and 69 y Mild to moderate physical impairments without cognitive deficits	Sample size varied between 19 and 63 participants. Descriptive analysis indicated no differences.	-	⊕OOO	Methodological quality of the studies indicated somewhat risk of bias. Clinical heterogeneity observed in the use of technology. Sample size in total<400. Only focusing on elderly persons with stroke with mild impairments without cognitive deficits.

Abbreviations: BI, Barthel Index; DVD, digital video disc; FONEFIM, telephone version of the FIM; ITT, intention to treat; MBI, Modified Barthel Index; MRS, Modified Rankin Scale; NEADL, Nottingham Extended Activities of Daily Living.

* GRADE was considered either high quality (4 plus), we are very confident that the true effect lies close to that of the estimate of the effect; moderate quality (3 plus), we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different; low quality (2 plus), our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect; very low quality (1 plus), we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

when compared to traditional therapies in stroke.[17,18] Results of our meta-analysis indicated a moderate statistical heterogeneity, which our analysis did not encompass for meta-regression due to lack of studies. Once more studies are published in this field, we might be able to investigate more specific factors that might enhance clinical and statistical heterogeneity, such as personal and clinical characteristics, comparison of different control groups (ie, usual care, similar, or other treatment), or more wide comparison of different technologies.

Our review showed inconsistent findings on walking. Two of 3 studies showed less improvement on walking for participants who received telephone-based distance physical rehabilitation interventions providing home-based exercises.[33,39] These interventions were compared to participants who received supervised clinic-based treadmill training[33] or leisure-center exercise training.[39] The third study found no differences between the groups, when distance physical rehabilitation interventions were instructed through online video monitoring and smartphone application compared with usual care.[44] Evidence of using technology-based physical rehabilitation interventions is still scarce in the research field. However, our findings could indicate that when aiming to improve walking ability in stroke, distance physical rehabilitation might not be an alternative option for stroke survivors. For other physical functioning outcomes (ie, upper and lower extremity, balance, physical activity, participation), our descriptive analyses indicated similar effects between technology-based distance physical rehabilitation interventions and the combination of traditional treatments. Unfortunately, we were not able to perform meaningful meta-analyses from these outcomes due to lack of studies and insufficient data. In previous systematic review with meta-analysis, only 2 studies showed similar results on upper extremity functioning and balance, when all types of telerehabilitation interventions were compared with traditional treatments in stroke.[18] Although our review was able to solely focus on physical rehabilitation interventions, more evidence is warranted on different technologies and their possible additional values over traditional physiotherapy or other forms of physical rehabilitation when only similar treatments are compared with the distinction only on the use of technology.

The overall methodological quality and the quality of evidence of the included studies were low. The included RCTs had main insufficient methodological quality for treatment allocation procedures, blinding of the participants and care providers, selection bias, prevention of cointerventions, and reporting of intervention compliance. The difficulty in blinding care providers or participants in these study types is understandable. Moreover, it may be difficult to prevent cointerventions completely, especially in the early stage of recovery among persons with stroke. Surprisingly, there was a lack of quality in reporting compliance to interventions. Guidelines such as CONSORT 2010 Statement for reporting an RCT study are strongly recommended to increase transparency and methodological quality of a single RCT study.[46] GRADE evaluation showed also low quality of evidence, suggesting that the confidence in the effect estimates was low and that future studies may substantially change the effect estimates.

Twelve out of 13 studies reported inclusion criteria of low or intermediate physical disability based on a measure of walking ability, upper extremity functioning, or overall physical functioning.[33-45] Also, the same studies included an inclusion criterion of no cognitive deficit at baseline.[33-45] Most of the participants were men with a mean age of 65 years, had a disease duration of 11 months, and 87% of the participants experienced ischemic stroke. These demographic and clinical characteristics suggest that our results can be generalized to elderly male stroke survivors in the subacute stage of a recovery with no cognitive impairment, and who can function independently at least in some levels of their daily life. Approximately from 50% to 75% of new stroke survivors develop some level of cognitive impairment.[47,48] From this perspective, the use of technology for providing distance rehabilitation interventions in persons with stroke may not always be suitable, due to the presence of cognitive impairment. Therefore, technology-based distance physical rehabilitation interventions are important to develop toward more stroke-specific, individualized, and user-friendly approaches to recognize who would benefit from the technology when the focus is to improve physical functioning in daily life.

In this systematic review, technology-based distance physical rehabilitation interventions were defined as interventions that used $\geq$1 technological devices in a remote guidance of a health care professional, mainly monitored by a physiotherapist. Eight included studies used real-time communication through online video monitoring or telephone calls. However, the included studies used different technologies or a combination of several technologies using different interaction methods, thus making it difficult to determine the advantage of a single interaction approach. Our review also indicated that there is a lack of evidence on the effectiveness of technology-based distance physical rehabilitation interventions in stroke rehabilitation, and the current use of technology, and its communication method is scarce in the research field. Future studies are recommended to narrow this gap to understand the benefits of either a single technology or a single interactive method (eg, self-monitoring vs interactive communication) enabled through a technology device in a distance physical rehabilitation intervention.

To understand the benefits of using technology in physical rehabilitation interventions, one must understand its benefits in resource utilization and cost-effectiveness.[19] Unfortunately, our systematic review did not observe any indication of these approaches in the included studies, which was consistent with that observed in previous similar systematic reviews.[17-19,49-51] These aspects are crucial for understanding whether technology-driven distance rehabilitation interventions are beneficial for the health care system without overlooking the meaningful and goal-orientated rehabilitation of persons with stroke. Therefore, future studies should also focus on the resource utilization and cost-effectiveness of technology-based distance physical rehabilitation interventions compared with traditional or similar treatments.

Study strengths and limitations

The strength of this systematic review and meta-analysis is its focus on technology-based distance physical rehabilitation in persons with stroke, because previous systematic reviews have mainly focused on telerehabilitation.[17-19] In this review, we strictly followed the inclusion criteria based on the PICOS framework to determine the effect of technology-based distance physical rehabilitation interventions in persons with stroke. We only included studies that used technology-based distance physical rehabilitation setting in 1 intervention group that were administered in the physical absence of a health care professional compared to a group that did not use any technology.

However, this systematic review has some limitations. The studies included in our review were heterogeneous with respect to the content of treatments in participants in the experimental and control groups. Heterogeneity was also reported in previous reviews assessing technology-based distance rehabilitation interventions.[49-51] Moreover, substantial variability was observed in technologies in the distance physical rehabilitation interventions. Because of these reasons, the results of this systematic review should be interpreted with caution. Nevertheless, this systematic review provides overview on the type of technologies used to enable distance physical rehabilitation interventions for improving physical functioning in stroke survivors, and hopefully, encourages researchers to conduct more studies in this field.

Conclusions

This systematic review suggests that the effectiveness of technology-based distance physical rehabilitation for improving ADL, upper and lower extremity functioning, balance, physical activity, and participation is similar compared to the traditional treatments in persons with stroke. Contradictory findings were observed for walking. Further research should be performed to confirm the effectiveness of technology-based distance physical rehabilitation interventions for improving physical functioning of persons with stroke.

Supplier

a. Review Manager 5.3.5; The Cochrane Collaboration.

Keywords

Rehabilitation; Remote rehabilitation; Stroke; Systematic review; Technology

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