J Telemed Telecare OnlineFirst, published on February 22, 2015 as doi:10.1177/1357633X15572201

Research Article

Journal of Telemedicine and Telecare
0(0) 1–12

DOI: 10.1177/1357633X15572201
jtt.sagepub.com

Telerehabilitation and recovery of motor function: a systematic review and meta-analysis

Michela Agostini[1], Lorenzo Moja[2], Rita Banzi[3], Vanna Pistotti[3], Paolo Tonin[1], Annalena Venneri[4,5] and Andrea Turolla[1,4]

Summary

Recent advances in telecommunication technologies have boosted the possibility to deliver rehabilitation via the internet (i.e. telerehabilitation). Several studies have shown that telerehabilitation is effective to improve clinical outcomes in disabling conditions. The aim of this review was to determine whether telerehabilitation was more effective than other modes of delivering rehabilitation to regain motor function, in different populations of patients.

We searched PubMed, Embase and the Cochrane library retrieving 2360 records. Twelve studies were included involving different populations (i.e. neurological, total knee arthroplasty (TKA), cardiac) of patients. Inconclusive finding were found on the effect of telerehabilitation for neurological patients (SMD = 0.08, CI 95% = −0.13, 0.29), while both for cardiac (SMD = 0.24, CI 95% = 0.04, 0.43) and TKA patients (Timed Up and Go test: MD = −5.17, CI 95% = −9.79, −0.55) the results were in favour of telerehabilitation.

Conclusive evidence on the efficacy of telerehabilitation for treatment of motor function, regardless of pathology, was not reached. Nevertheless, a strong positive effect was found for patients following orthopaedic surgery, suggesting that the increased intensity provided by telerehabilitation is a promising option to be offered to patients. More and higher quality research is needed in this field especially with neurological patients.

Keywords

Systematic Review, Telerehabilitation

Date received: 16 August 2014; accepted: 15 November 2014

Background

The increasing availability of low cost internet and communication technologies (ICT) (e.g. ADSL, HDSL, fiber connection) has boosted the opportunity to apply technology-based solutions to provide health services during hospitalisation and after discharge from hospital. This approach, broadly referred to as telemedicine, may guarantee better continuity of care from hospital to patients' home, as well as patients' monitoring and counselling.[1] ICTs has become a valuable option also for rehabilitation supporting the birth of a new branch of telemedicine, called telerehabilitation.[2,3]

Telerehabilitation involves the remote delivery of different rehabilitation services via telecommunications technology.[4] It can provide interventions such as physiotherapy, speech therapy, occupational therapy, patient telemonitoring and teleconsultation, thus providing assistance to homebound patients without the physical presence of a therapists or other health professionals.[5] Benefits of telerehabilitation include the delivery of prolonged therapies tailored on patients' needs while at the same time making significant savings on costs. A number of trials have been published to test the feasibility of telerehabilitation approaches and to compare their effectiveness with standard rehabilitation practice. Recent small randomized trials (RCTs) of rehabilitation of motor function after surgery demonstrated that treatment delivered

[1]Foundation IRCCS San Camillo Hospital, Laboratory of Kinematics and Robotics, Neurorehabilitation Department, via Alberoni 70, 30126, Venice, Italy
[2]Department of Biomedical Sciences for Health, University of Milan, Milan, Italy; Clinical Epidemiology Unit, IRCCS Orthopedic Institute Galeazzi, Milan, Italy
[3]IRCCS-Istituto di Ricerche Farmacologiche "Mario Negri", Via La Masa 19, 20156 Milan, Italy
[4]Department of Neuroscience, The University of Sheffield. Sheffield, UK
[5]Foundation IRCCS San Camillo Hospital, Laboratory of Neuroimaging, via Alberoni 70, 30126, Venice, Italy

Corresponding author:
Michela Agostini, Via Alberoni, 70 - 30126 - Venezia Lido, VE. Italy.
Email: michela.agostini@ospedalesancamillo.net

via telerehabilitation achieved similar results to therapy delivered via standard care.[6,7] Functional magnetic resonance imaging (fMRI) showed that rehabilitative treatments provided via telerehabilitation activate the same cortical regions as conventional treatment.[8] Previous studies of telerehabilitation for the treatment of upper limb motor function after stroke confirmed these data.[4] Several authors observed that the use of telerehabilitation leads to high levels of satisfaction as reported by patients,[9,10] reinforcing the hypothesis that the delivery of rehabilitative services at a distance is a feasible alternative to routine care. The conclusions from the above evidence suggest that telerehabilitation offers an opportunity for equitable access to rehabilitation services for individuals living in remote areas or unable to reach local health providers because of physical impairments.[10] Furthermore, telerehabilitation would limit unnecessary hospital admissions or delays in discharging patients at home.

Despite satisfactory scientific results and recommendations from national health plans to reduce costs by shortening hospital stays, telerehabilitation is still not widely disseminated. One of the reason explaining the current gap between scientific evidence and clinical deployment of telerehabilitation services relies on the technical requirements needed for settling a therapeutic environment at a distance. First, the flexibility of devices is fundamental to provide the different therapeutic modalities needed in the wide range of impairments. Second, a broad connectivity coverage is needed to reach most users at home. To date, reviews of the scientific literature on telerehabilitation are qualitative syntheses mainly addressing issues related to neurological rehabilitation.[11–14] Recently, Laver and colleagues published the first systematic review with meta-analysis of telerehabilitation services for stroke.[15] The authors concluded that insufficient evidence is available about the effectiveness of telerehabilitation after stroke, moreover no data on cost-effectiveness were found. On this basis, it is still difficult to argue the efficacy of telerehabilitation treatments provided at a distance, when compared to standard rehabilitation care provided in person.

Objectives

The aim of this review was to compare the effectiveness of telerehabilitation programmes with standard rehabilitation treatments (i.e. provided in the presence of health professionals) in terms of recovery of motor function across diseases.

Methods

Search strategy

We searched PubMed (1946-January 2014), Embase (1974-January 2014), the Cochrane Central Register of Controlled Trials (CENTRAL, January 2014) for publications written in English and Italian. We identified published, unpublished and ongoing trials, by hand searching the reference lists from relevant articles and by contacting investigators known to be involved in this research area. Details of search terms and strategies are available in appendix 1.

Selection criteria

Studies were eligible for inclusion if testing telerehabilitation for the recovery of the motor function (measured by means of different scales), in patients affected by any type of impairment or disease. In the context of this systematic review, telerehabilitation is considered as:

- provided by means of any kind of technological device allowing healthcare professional/patient interaction both on-line or off-line;
- provided by healthcare professionals or caregivers through remote supervision;
- including at least one specific intervention targeted to rehabilitation (e.g. remotely controlled virtual reality motor training, occupational exercises at home through sensorized devices).

Telerehabilitation could be compared to (1) intervention; (2) rehabilitation therapies provided face-to-face independently of setting of delivery (home, hospital, ambulatory); (3) usual care.

We included RCTs or quasi-RCTs and controlled clinical trial (CCT) with or without blinding of assessor(s). In cross-over trials, we included only the first phase of studies to exclude any carry-over or learning effects.

Data collection and analysis

Two authors (MA and AT) independently screened the title and abstract of the records retrieved from the search strategy, applying the selection criteria previously described. The full text of the possible eligible records were retrieved and analysed for final inclusion in this systematic review. Any disagreement was resolved through discussion and contacting a third author (LM), if needed. Two authors (MA and AT) independently extracted the data from the included studies, using a standard form and summarised them in Table 1. The items extracted were: details of the participants (i.e. age, gender, type of disease); inclusion/exclusion criteria for patients' eligibility; duration, intensity and frequency of interventions and controls; description of telerehabilitation programme; outcomes assessed.

Both the experimental and control treatments provided to participants were reported with as many details as possible. If needed, the trials' author was contacted to ask for clarification and to obtain missing data.

Data on motor function scores were extracted and pooled in a meta-analysis using the Cochrane

Table 1. Characteristics of the included studies.

Author, year	Population	Patients (exp/ctrl)	Experimental intervention	Control intervention	Motor function outcome	Outcome construct	Other outcomes	Follow-up
Hermens, 2007	Stroke TBI MS	81 (55/26)	30' daily sessions; 5d/w HCAD	Usual care	ARAT	UE function	NHPT; WMFT	4 weeks
Huijen, 2008	Stroke TBI MS	81 (55/26)	30' daily sessions; 5d/w HCAD	Usual care	ARAT	UE function	NHPT; VAS satisfaction	4 weeks
Piron, 2008	Stroke	10 (5/5)	1 h daily; 5d/w (20 sessions) Remotely controlled VR	VR at home	F-M UE	UE motor function	Satisfaction	4 weeks
Dallolio, 2008	SCI	137 (62/65)	45'; 8 d/w (2 m) + 2d/w (4 m) Clinical counselling and OT	Usual care at home	FIM	Independence	SCIM II; Satisfaction	24 weeks
Barnason, 2009	Elderly after CABS	280 (143/137)	7 daily sessions/w (42 sessions) Subjects provided with symptom management strategies	Usual care	MOS SF-36 (physical functioning sub scale)	Motor function, Independence, QoL	Modified 7-Day Activity Interview; RT3 accelerometer; diary (health care use)	6 weeks
Piron, 2009	Stroke	36 (18/18)	1 h daily; 5d/w (20 sessions) Remotely controlled VR	Usual care at home	F-M UE	UE motor function	Ashworth; Abilhand	4 weeks
Furber, 2010	Cardiac parients	222 (109/113)	daily sessions Pedometer, self-monitoring, telephone and mail support	Usual care	Active Australia Questionnaire	Sel-reported physical activity	Kessler 6 scale	6 weeks
Russell, 2011	Total knee arthroplasty	65 (31/34)	45' daily sessions Exercises programme; education for postoperative management provided by PT	Usual care at the PT department	TUG	Mobility, balance, walking ability	Patient-Specific Functional Scale; WOMAC; Pain Intesity; Knee Flex/Ext; Strength (quadriceps); Limb girth; Gait	6 weeks
Tousignant, 2011	Total knee arthroplasty	48 (24/24)	1 h twice a week Functional exercises programme	Usual care at home	TUG	Mobility, balance, walking ability	ROM; BBS; 30' Chair-stand Test; WOMAC; Tinetti; SMAF; MOS SF-36	8 weeks
Gutierrez, 2013	MS	47 (24/23)	10w, 4 sessions/w, 20'/session	40' twice a week PT (low-loads	BBS	Mobility, balance, walking ability	Tinetti, VAS fatigue, SOT test	10 weeks

(continued)

Table 1. Continued

Author, year	Population	Patients (exp/ctrl)	Experimental intervention	Control intervention	Motor function outcome	Outcome construct	Other outcomes	Follow-up
			(40 sessions) Xbox360® console with Microsoft® Kinect (i.e. Kinect Sports®, Joy Ride®, Adventures®	strength, proprioception, stretching exercises)				
Chumbler, 2012	Stroke	48 (25/23)	3 months STeleR: 3 home televisits, daily IHMD, VA.	Usual care (VA) at home.	Motor FONEFIM (telephone version of FIM)	Independence	LLFDI: upper extremity, disability	3 months
Piqueras, 2013	Total knee arthroplasty	181 (90/91)	1 h sessions for 10d IVT	Standard rehabilitation	TUG	Mobility, balance, walking ability	ROM; dynamometer; VAS pain; WOMAC	10 days

exp: experimental; ctrl: control; CABS: coronary artery bypass surgery; MOS SF-36: medical outcomes study short form 36; QoL: quality of life; TBI: traumatic brain injury; MS: multiple sclerosis; ARAT: action research arm test; UE: upper extremity; NHPT: nine hole pegboard test; WMFT: Wolf motor function test; PT: physical therapist; WOMAC: Western Ontario and McMaster universities osteoarthritis index; TUG: timed up and go test; VR: virtual reality; F-M: Fugl-Meyer scale; SCI: spinal cord injury; OT: occupational therapy; FIM: functional independence measure; SCIM II: spinal cord independence measure II; ROM: range of movement; BBS: Berg balance scale; SMAF: functional autonomy measurement system; SOT: sensory organization test; IHMD: in-home messaging device; VA: Veteran Affair; LLFDI: Overall Function Component of the Late-Life Function and Disability Instrument; IVT: Interactive Virtual Telerehabilitation.

Collaboration's Review Manager software (RevMan 5.0). Whenever available, the results from intention-to-treat (ITT) analyses were extracted and pooled. As motor function is widely assessed through scores on different continuous scales, we pooled the data using the standardised mean difference (SMD) and 95% confidence intervals (CI). In those cases when the same outcome was used in different trials the mean difference (MD) and 95% CI were used for meta-analysis. We analysed the studies according to the type of population included (e.g. neurological, surgical, cardiac patients). Heterogeneity was determined using the I-squared (I^2) statistic (I^2 greater than 50% was considered as substantial heterogeneity). When heterogeneity was present, data were pooled using a random-effect model and potential causes explored through subgroup analysis.

Quality assessment

Two authors (MA and AT) independently evaluated the methodological quality of the included studies, using a standardised critical appraisal assessment form. Quality assessment of studies was focused on areas of bias which might overestimate the effectiveness of interventions. The following domains were considered as relevant: random sequence generation; allocation concealment; baseline comparison between groups; blinding of outcome assessment; incomplete outcome data (attrition and ITT analysis). The results are summarised in the risk of bias table (Figure 5).

Results

Studies selection

The literature search retrieved 2360 records (i.e. Pubmed = 1674; Embase = 510; CENTRAL = 176). With regard to crucial keywords such as, "telemonitored rehabilitation" and "telemonitored exercise training", independent searches retrieved 8 and 3 records, respectively. Nevertheless, these records contained "telemedicine" as MeSH descriptor that has been included in our search strategy.

After the removal of duplicates, we screened the title and abstract of 2150 references and selected 76 papers (1 full text was not retrieved[16]) for which we assessed the full text for final inclusion. Among these 64 papers were excluded for the following reasons: 35 because the ICTs used were not aimed to rehabilitation purposes;[17–51] eight papers were protocols of ongoing studies and results were not available;[52–59] seven studies did not have a control group;[60–66] five because the intervention setting was the same in the two groups;[8,67–70] five were pilot studies;[71–75] two were secondary analysis of RCTs already included;[76,77] two studies were excluded because the poor reporting precluded any possible assessment of its eligibility.[78,79] Finally, 12 RCTs for a total of 1047 participants were included in the review (Figure 1).

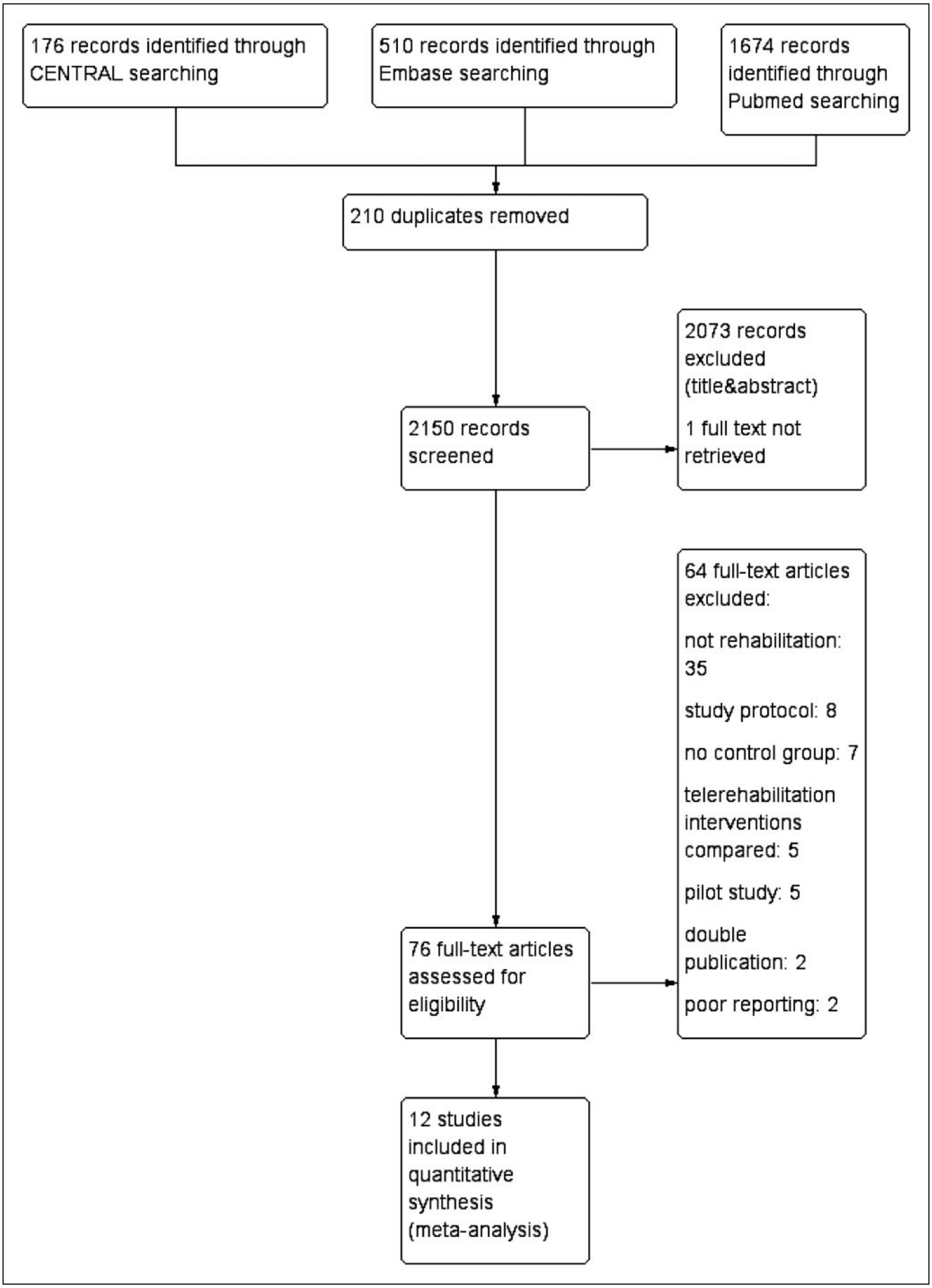

Figure 1. Literature flowchart.

Characteristics of the included studies

The main characteristics of RCTs included are described in Table 1. Ten studies compared telerehabilitation with usual care provided at home or hospital,[9,80–88] while two studies compared the same intervention provided via telerehabilitation or face-to-face by therapists.[4,7] The best outcome measure assessing motor function was extracted, regardless of its definition as primary outcome. In all the studies motor function was assessed before and after all treatments. Five trials also reported later follow-up assessments at 1,[9,89] 3[87] and 6 months[81,86] after the end of treatment. We did not consider longer follow-up in the meta-analysis. With regard to the populations involved, seven studies focused on patients affected by neurological diseases,[9,81,83,84,86,88,89] three on patients following total knee arthroplasty (TKA) surgery[7,87,90] and two enrolled cardiac patients.[80,82]

Risk of bias assessment

Figure 5 summaries the assessment of the methodological quality of the included studies. There were only RCTs and all but three[80,87,88] were at low risk of selection bias due to an adequate random sequence generation and allocation of the randomisation sequence. Baseline characteristics between groups were comparable in all the included trials. Blinding of outcome assessment was judged not adequate in four trials.[4,80,83,84] Attrition bias was absent only in three trials[9,86,90] in which no patients were lost at follow up and consequently ITT and per-protocol analysis were coincident.

Effects of interventions

Overall the meta-analyses included 543 participants receiving telerehabilitation compared with 520 participants receiving control treatments. No significant difference between the groups was found (SMD = −0.08, CI 95% = −0.43, 0.27). Moreover, a high level of heterogeneity ($I^2 = 85\%$) affected the meta-analysis which depended on the broad difference of populations enrolled. To take this into account, three different meta-analyses were run grouping the studies with the same populations. The effect of telerehabilitation on motor function is displayed in figures 2 to 4 for neurological, TKA and cardiac populations, respectively. Dallolio et al. reported no overall data but split the results in three subgroups.

Telerehabilitation was more effective than control treatments for regaining motor function, when provided to patients following TKA surgery (Timed Up and Go test: MD = −5.17, CI 95% = −9.79, −0.55). This result was mostly driven by the highly positive study by Piqueras and colleagues, which was judged at high risk of selection and attrition biases. In patients with cardiac diseases, there was a more plausible small effect favouring telerehabilitation (SMD = 0.24, CI 95% = 0.04, 0.43). However, these data are based on two trials only. Similarly to Laver and collegues, no significant different effects were found between telerehabilitation and other interventions when used for the treatment of neurological diseases (SMD = 0.10, CI 95% = −0.24, 0.43). All the meta-analyses were displayed sorted by incremental effect sizes. The visual inspection of forest plots showed that direction of efficacy was influenced by magnitude of effect size, being the studies with biggest effect sizes in favour of telerehabilitation. Nevertheless, none of the studies, except one,[87] resulted as statistically significant by itself.

Studies of cardiac patients were homogeneous while heterogeneity was high among neurological ($I^2 = 54\%$) and TKA ($I^2 = 84\%$) studies, thus results from random effects models are displayed in figures 2 and 3. Nevertheless, neither random effects models explained

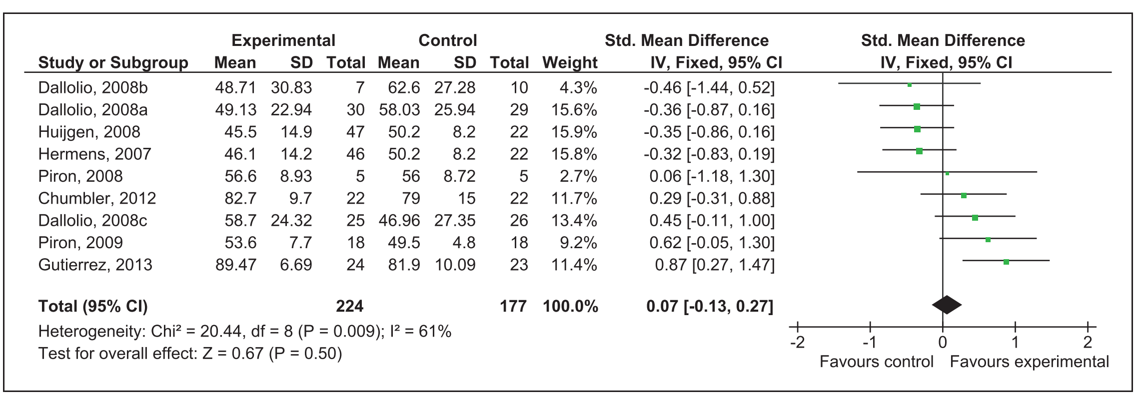

Figure 2. Effect of telerehabilitation on motor function for neurological patients.
The study from Dallolio et al. (2008) was split in three different studies given that reporting of results for the overall groups was missing.

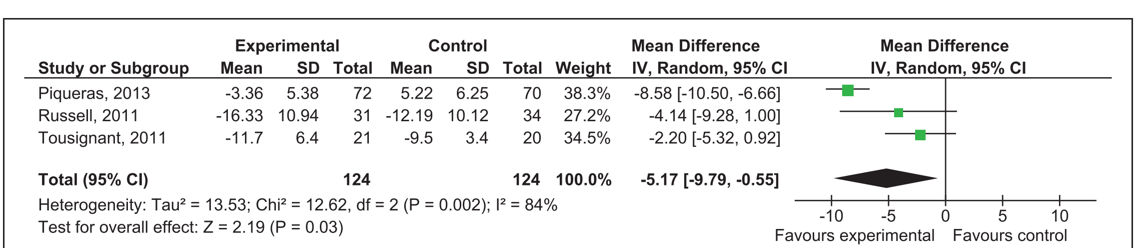

Figure 3. Effect of telerehabilitation on the Timed Up and Go test after total knee arthroplasty.

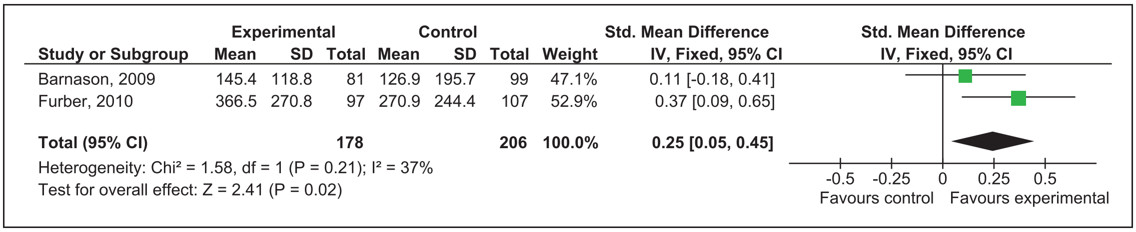

Figure 4. Effect of telerehabilitation on motor function for cardiac patients.

such heterogeneity, thus the reasons were explored through subgroup analysis, finding that it dropped down to 0% removing the studies affected by higher risk of biases, both in neurological[83,84,88] and TKA[87] meta-analyses. Nevertheless, the removal of low quality studies did not change the results of the meta-analyses both for neurological (6 studies: SMD = 0.16, CI 95% = −0.12, 0.44) and TKA (Timed Up and Go test, 2 studies: MD = −2.72, CI 95% = −5.39, −0.06) populations.

Discussion

In this study the scientific literature was systematically reviewed to retrieve controlled trials comparing telerehabilitation with other treatments. The aim of the systematic review was to determine whether telerehabilitation was more effective than other rehabilitation modalities to regain motor function, in different populations of patients. It has to be acknowledged that we chose to distinguish telerehabilitation from other telemedicine applications (e.g. telemonitoring, teleradiology) because of the possibility of providing therapeutic interventions, remotely controlled by healthcare professionals, with a rehabilitation purpose. In our definition the aim of telerehabilitation is to augment the intensity and the providing of rehabilitation care after discharge, to guarantee continuity of care from hospital to patient's home and to reduce costs. With this definition, the variety of populations included in this review could be intended as joined by common needs typical of chronic conditions (i.e. reductions of: physical activity, coping, clinical outcomes; increase of: hospital stay, hospital readmission rate, mortality).[91]

The picture depicted by this systematic analysis indicates that the most extensive application for telerehabilitation was developed and tested with survivors from traumatic, degenerative and vascular diseases of the central nervous system (CNS), like: spinal cord injury, traumatic brain injury, multiple sclerosis and stroke.

An interesting finding from our meta-analysis is the significant positive effect of telerehabilitation in the post TKA surgery population. When measured by TUG test a researcher would expect patients treated by telerehabilitation to improve 6.5 seconds more than patients treated routinely, on average. Although a minimally clinically important difference for TUG test in post TKA surgery patients was not established in this study, our result is bigger than the standard error of measurements reported for other populations, thus reducing the chance that the same result was just due to an intrinsic variability of the outcome. A possible explanation for our finding could be due to the follow up time between 2 and 8 weeks for all the TKA studies, that represents a more homogeneous comparison than the follow up range reported for the neurological population (i.e. between 4 and 24 weeks) and a feasible time for recovery after knee surgery. Moreover, telerehabilitation provides a concrete opportunity to increase the amount and intensity of rehabilitation experienced by patients, a factor that is known to be a positive predictor of recovery after surgery.

Overall, our results were influenced by the chosen inclusion criteria deliberately set to exclude all telemedicine applications not devoted to therapy and not provided by healthcare professionals. These criteria determined the difference between the studies included in our study than the ones included by the Cochrane stroke group in its recently published review of telerehabilitation services for stroke.[15] Another difference between the two reviews is related to the choice of outcomes. Whilst Laver and co-workers focused their work on a broad range of clinical outcomes (i.e. ADLs, independence, mobility, QoL, upper limb function, cognitive function, communication), our choice was to detail the effect of telerehabilitation on recovery of motor function amongst different populations. Nevertheless, in both reviews the studies retrieved were small and frequently biased by lack of outcome assessor blinding and lack of allocation concealment.

Limitations

Several limitations of this review should be acknowledged. Despite the most extensive application for telerehabilitation was developed and tested with survivors from traumatic, degenerative and vascular diseases of the central nervous system (CNS), most of the studies in the neurorehabilitation field are marked by small sample sizes, large variability of results and consistent presence of biases representing the main source of heterogeneity in this meta-analysis. Despite the literature on neurorehabilitation represents the largest in terms of studies retrieved (n = 7), the patients enrolled overall (n = 385) were less than the patients enrolled in the 2 studies retrieved for the cardiac population (n = 414). The limit of small samples is common in the neurorehabilitation literature,[92] because of the difficulties in predicting prognosis, the broad range of disability experienced by patients, the burden

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Baseline comparison between groups	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)
Barnason, 2009	−	−	+	−	−
Chumbler, 2012	+	+	+	+	+
Dallolio, 2008a	+	+	+	+	−
Dallolio, 2008b	+	+	+	+	−
Dallolio, 2008c	+	+	+	+	−
Furber, 2010	+	+	+	+	−
Gutierrez, 2013	−	−	+	+	−
Hermens, 2007	+	+	+	−	−
Huijgen, 2008	+	+	+	−	−
Piqueras, 2013	−	−	+	+	−
Piron, 2008	+	+	+	+	+
Piron, 2009	+	+	+	−	−
Russell, 2011	+	+	+	+	+
Tousignant, 2011	+	+	+	+	−

Figure 5. Risk of bias table.
Red = high risk of bias; Green = low risk of bias.

of care on caregivers and the long time needed to observe meaningful changes of clinical outcomes.[93] As a consequence, the enrolment of patients is more challenging for researcher in the neurorehabilitation field, than in other specialties related to rehabilitation.

Another finding from this review was the paucity of eligible trials on telerehabilitation for cardiac patients. The literature on telemedicine for heart failure survivors is wide and has been consolidated for many years. Nevertheless, the major part of clinical trials in this field aimed to improve: reliability of monitoring at a distance, adherence to lifelong therapeutic programs, levels of physical activity, with the aim to reduce risk factors and mortality. Only a minority of trials aimed to study active rehabilitation therapies for cardiac patients. Another limitation for cardiac patients was the selection of questionnaires instead of tests for the assessment of motor function. The choice was based on two main reasons: firstly, in Barnason et al. only SF-36 data were available for all the patients, thus reducing the attrition bias related to reporting per-protocol analysis; secondly, existing available evidence suggest that telemonitoring is effective in cardiac patients to increase the motor activity and function, as measured by tests. Given these limitations, our final choice was to assess whether the objective improvement of motor function was subjectively perceived with self-reported outcome measures (fully reported in both papers). Indeed, only motor components of questionnaires were considered for meta-analysis. Our choice was also based on the evidence that meta-analysis for homogeneous outcome measures (i.e. minutes of physical activity) has been run confirming the result in favour of telerehabilitation (SMD = 0.25 [0.05-0.45]), but with moderate heterogeneity (I2 = 37%) and presumably affected by attrition bias in primary studies. In conclusion we chose to stay conservative reporting a more robust meta-analysis based on new findings not present in the literature.

In the end, the most popular electronic databases were searched for this review, but telerehabilitation is emerging as a transversal topic throughout healthcare professionals, thus other databases specific for different disciplines could have been included to achieve a broader coverage (e.g. CINAHL, psycINFO, PEDro) of the literature. Moreover, only trials reported in English and in Italian were included, restricting the raw dataset of records used for screening.

Conclusion

Our meta-analysis was not conclusive and did not provide final evidence on the efficacy of telerehabilitation in motor function recovery. Several position statements have been published about telerehabilitation in the last few years,[94,95] highlighting the need for standardization of procedures, aims and targets characterizing this therapeutic modality. Considering the growing burden of care within national health systems and the need to guarantee adequate and continue services to chronic conditions, telerehabilitation is becoming an interesting model of care, whose potential deployment needs to be studied. To understand whether the growing dissemination of ICTs infrastructures may be adequate for the deployment of innovative rehabilitation services based on the internet, robust trials have to be designed and carried out, to avoid waste of resources and the risk of inconclusive findings from primary research. Moreover, future trials on telerehabilitation should include costs accountability and cost-effectiveness analyses, associated with clinical findings. The main potentiality of telerehabilitation is the possibility to increase the frequency and intensity of care provided to patients and consequently to motivate clients in their own home environment. The current data are encouraging and support continuity of rehabilitation care through ICTs, but the quality of primary research has to be improved dramatically to have a clearer picture of benefits and risks associated with assisting patients at a distance, once discharged at home.

Disclosure Policy

The authors declare that there is no conflict of interests regarding the publication of this article.

The authors, Agostini Michela and Andrea Turolla, declare that they are the co-authors in the two studies included in this Systematic Review (i.e. Piron 2008 e 2009) [4–9]

Acknowledgements

We wish to thank Michel Tousignant, who generously provided additional details from his study and assisted us with the preparation of this review.

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

1. Palsbo SE, Bauer D. Telerehabilitation: managed care's new opportunity. *Manag Care Q* 2000;**8**:56–64.
2. Rosen MJ. Telerehabilitation. *Telemedicine Journal and E-health: The Official Journal of the American Telemedicine Association* 2004;**10**:115–17.
3. Dhurjaty S. The economics of telerehabilitation. *Telemedicine Journal and E-health: The Official Journal of the American Telemedicine Association* 2004;**10**:196–9.
4. Piron L, Turolla A, Agostini M, et al. Exercises for paretic upper limb after stroke: a combined virtual-reality and telemedicine approach. *J Rehabil Med* 2009;**41**:1016–102.
5. Piron L, Tonin P, Trivello E, Battistin L, Dam M. Motor tele-rehabilitation in post-stroke patients. *Med Inform Internet Med* 2004;**29**:119–25.
6. Chumbler NR, Quigley P, Li X, et al. Effects of telerehabilitation on physical function and disability for stroke patients: a randomized, controlled trial. *Stroke* 2012;**43**:2168–74.
7. Tousignant M, Moffet H, Boissy P, Corriveau H, Cabana F, Marquis F. A randomized controlled trial of home telerehabilitation for post-knee arthroplasty. *J Telemed Telecare* 2011;**17**:195–8.
8. Carey JR, Durfee WK, Bhatt E, et al. Comparison of finger tracking versus simple movement training via telerehabilitation to alter hand function and cortical reorganization after stroke. *Neurorehabil Neural Repair* 2007;**21**:216–32.
9. Piron L, Turolla A, Tonin P, Piccione F, Lain L, Dam M. Satisfaction with care in post-stroke patients undergoing a telerehabilitation programme at home. *J Telemed Telecare* 2008;**14**:257–60.
10. Keith CG, Ekert H. The management of retinoblastoma. *Australian and New Zealand journal of ophthalmology* 1987;**15**:359–63.
11. Hailey D, Roine R, Ohinmaa A, Dennett L. Evidence of benefit from telerehabilitation in routine care: a systematic review. *Journal of Telemedicine and Telecare* 2011;**17**:281–7.
12. Rogante M, Grigioni M, Cordella D, Giacomozzi C. Ten years of telerehabilitation: A literature overview of technologies and clinical applications. *NeuroRehabilitation* 2010;**27**:287–304.
13. Kairy D, Lehoux P, Vincent C, Visintin M. A systematic review of clinical outcomes, clinical process, healthcare utilization and costs associated with telerehabilitation. *Disability and Rehabilitation* 2009;**31**:427–47.
14. Johansson T, Wild C. Telerehabilitation in stroke care–a systematic review. *J Telemed Telecare* 2011;**17**:1–6.
15. Laver KE, Schoene D, Crotty M, George S, Lannin NA, Sherrington C. Telerehabilitation services for stroke. *Cochrane Database Syst Rev* 2013;**12**:CD010255.
16. Peters S, Hentschke C, Pfeifer K. [Internet-based "e-training" as exercise intervention for health promotion: results from 2 intervention studies]. *Rehabilitation (Stuttg)* 2013;**52**:173–81.
17. Audebert HJ, Schenkel J, Heuschmann PU, Bogdahn U, Haberl RL. Effects of the implementation of a telemedical stroke network: the Telemedic Pilot Project for Integrative Stroke Care (TEMPiS) in Bavaria, Germany. *Lancet Neurol* 2006;**5**:742–8.
18. Schein RM, Schmeler MR, Holm MB, Saptono A, Brienza DM. Telerehabilitation wheeled mobility and seating assessments compared with in person. *Arch Phys Med Rehabil* 2010;**91**:874–8.
19. Dansky KH, Palmer L, Shea D, Bowles KH. Cost analysis of telehomecare. *Telemed J E Health* 2001;**7**:225–32.
20. Devineni T, Blanchard EB. A randomized controlled trial of an internet-based treatment for chronic headache. *Behav Res Ther* 2005;**43**:277–92.
21. Egner A, Phillips VL, Vora R, Wiggers E. Depression, fatigue, and health-related quality of life among people with advanced multiple sclerosis: results from an exploratory telerehabilitation study. *NeuroRehabilitation* 2003;**18**:125–33.
22. Finkelstein SM, Speedie SM, Demiris G, Veen M, Lundgren JM, Potthoff S. Telehomecare: quality, perception, satisfaction. *Telemed J E Health* 2004;**10**:122–8.
23. Trautmann E, Kroner-Herwig B. A randomized controlled trial of Internet-based self-help training for recurrent headache in childhood and adolescence. *Behav Res Ther* 2010;**48**:28–37.
24. Sandsjo L, Larsman P, Huis in 't Veld RM, Vollenbroek-Hutten MM. Clinical evaluation of a myofeedback-based teletreatment service applied in the workplace: a randomized controlled trial. *J Telemed Telecare* 2010;**16**:329–35.
25. Huis in 't Veld RM, Kosterink SM, Barbe T, Lindegard A, Marecek T, Vollenbroek-Hutten MM. Relation between patient satisfaction, compliance and the clinical benefit of a teletreatment application for chronic pain. *J Telemed Telecare* 2010;**16**:322–8.
26. Kosterink SM, Huis in 't Veld RM, Cagnie B, Hasenbring M, Vollenbroek-Hutten MM. The clinical effectiveness of a

myofeedback-based teletreatment service in patients with non-specific neck and shoulder pain: a randomized controlled trial. *J Telemed Telecare* 2010;**16**:316–21.
27. Demaerschalk BM, Bobrow BJ, Raman R, et al. Stroke team remote evaluation using a digital observation camera in Arizona: the initial mayo clinic experience trial. *Stroke* 41:1251–8.
28. Dorsey ER, Deuel LM, Voss TS, et al. Increasing access to specialty care: A pilot, randomized controlled trial of telemedicine for Parkinson's disease. *Movement Disorders* 25:1652–9.
29. Von Bonsdorff MB, Leinonen R, Kujala UM, et al. Effect of physical activity counseling on disability in older people: A 2-year randomized controlled trial. *Journal of the American Geriatrics Society* 2008;**56**:2188–94.
30. Williams DA, Kuper D, Segar M, Mohan N, Sheth M, Clauw DJ. Internet-enhanced management of fibromyalgia: a randomized controlled trial. *Pain* 151:694–702.
31. Wong YK, Hui E, Woo J. A community-based exercise programme for older persons with knee pain using telemedicine. *J Telemed Telecare* 2005;**11**:310–15.
32. Phillips VL, Vesmarovich S, Hauber R, Wiggers E, Egner A. Telehealth: Reaching out to newly injured spinal cord patients. *Public Health Reports* 2001;**116**:94–102.
33. Hoffmann T, Russell T, Thompson L, Vincent A, Nelson M. Using the Internet to assess activities of daily living and hand function in people with Parkinson's disease. *NeuroRehabilitation* 2008;**23**:253–61.
34. Holland AE, Hill CJ, Conron M, Munro P, McDonald CF. Short term improvement in exercise capacity and symptoms following exercise training in interstitial lung disease. *Thorax* 2008;**63**:549–54.
35. Akematsu Y, Tsuji M. Relation between telecare implementation and number of treatment days in a Japanese town. *J Telemed Telecare* 2013;**19**:36–9.
36. Cerrada C, Weinberg J, Dresner D, Boah A, Sherman K and Saper R. Comparison of paper surveys and computer-assisted telephone interviews in a randomized controlled trial of yoga for low back pain. *BMC Complementary and Alternative Medicine*. 2012; 12.
37. Dlugonski D, Motl RW, Mohr DC, Sandroff BM. Internet-delivered behavioral intervention to increase physical activity in persons with multiple sclerosis: sustainability and secondary outcomes. *Psychol Health Med* 2012;**17**:636–51.
38. Eakin EG, Lawler SP, Winkler EA, Hayes SC. A randomized trial of a telephone-delivered exercise intervention for non-urban dwelling women newly diagnosed with breast cancer: exercise for health. *Ann Behav Med* 2012;**43**:229–38.
39. Finkelstein SM, Speedie SM, Zhou X, Potthoff S, Ratner ER. Perception, satisfaction and utilization of the VALUE home telehealth service. *J Telemed Telecare* 2011;**17**:288–92.
40. Finlayson M, Preissner K, Cho C, Plow M. Randomized trial of a teleconference-delivered fatigue management program for people with multiple sclerosis. *Mult Scler* 2011;**17**:1130–40.
41. Houlihan BV, Jette A, Ni P, et al. Efficacy of nullcare callnull telerehabilitation intervention for persons with spinal cord dysfunction: Randomized controlled trial. *Archives of Physical Medicine and Rehabilitation* 2011;**92**:1690.
42. Jackson JC, Ely EW, Morey MC, et al. Cognitive and physical rehabilitation of intensive care unit survivors: results of the RETURN randomized controlled pilot investigation. *Crit Care Med* 2012;**40**:1088–97.
43. Kraal JJ, Peek N, van den Akker-Van Marle ME and Kemps HMC. Effects and costs of home-based training with telemonitoring guidance in low to moderate risk patients entering cardiac rehabilitation: The FIT@Home study. *BMC Cardiovascular Disorders*. 2013; 13.
44. Moessner M, Schiltenwolf M, Neubauer E. Internet-based aftercare for patients with back pain-a pilot study. *Telemed J E Health* 2012;**18**:413–9.
45. Nield M, Hoo GW. Real-time telehealth for COPD self-management using Skype. *COPD* 2012;**9**:611–9.
46. Palacin-Marin F, Esteban-Moreno B, Olea N, Herrera-Viedma E, Arroyo-Morales M. Agreement between telerehabilitation and face-to-face clinical outcome assessments for low back pain in primary care. *Spine (Phila Pa 1976)* 2013;**38**:947–52.
47. Salazar-Fernandez CI, Herce J, Garcia-Palma A, Delgado J, Martin JF, Soto T. Telemedicine as an effective tool for the management of temporomandibular joint disorders. *J Oral Maxillofac Surg* 2012;**70**:295–301.
48. Salisbury C, Foster NE, Hopper C, et al. A pragmatic randomised controlled trial of the effectiveness and cost-effectiveness of 'PhysioDirect' telephone assessment and advice services for physiotherapy. *Health Technol Assess* 2013;**17**:1–157, v-vi.
49. Sparrow D, Gottlieb DJ, Demolles D, Fielding RA. Increases in muscle strength and balance using a resistance training program administered via a telecommunications system in older adults. *J Gerontol A Biol Sci Med Sci* 2011;**66**:1251–7.
50. Tabak M, Vollenbroek-Hutten MM, van der Valk PD, van der Palen J and Hermens HJ. A telerehabilitation intervention for patients with Chronic Obstructive Pulmonary Disease: a randomized controlled pilot trial. *Clin Rehabil*. 2013.
51. Tousignant M, Boissy P, Moffet H, et al. Patients' satisfaction of healthcare services and perception with in-home telerehabilitation and physiotherapists' satisfaction toward technology for post-knee arthroplasty: an embedded study in a randomized trial. *Telemed J E Health* 2011;**17**:376–82.
52. Chumbler NR, Rose DK, Griffiths P, et al. Study protocol: home-based telehealth stroke care: a randomized trial for veterans. *Trials* 2010;**11**:74.
53. Schein RM, Schmeler MR, Brienza D, Saptono A, Parmanto B. Development of a service delivery protocol used for remote wheelchair consultation via telerehabilitation. *Telemed J E Health* 2008;**14**:932–8.
54. Rochette A, Korner-Bitensky N, Bishop D, et al. Study protocol of the YOU CALL–WE CALL TRIAL: impact of a multimodal support intervention after a "mild" stroke. *BMC Neurol* 10: 3.
55. Walters DL, Sarela A, Fairfull A, et al. A mobile phone-based care model for outpatient cardiac rehabilitation: the care assessment platform (CAP). *BMC Cardiovasc Disord*. 10: 5.
56. Galiano-Castillo N, Ariza-Garcia A, Cantarero-Villanueva I, et al. Telehealth system (e-CUIDATE) to improve quality of life in breast cancer survivors: rationale and study protocol for a randomized clinical trial. *Trials* 2013;**14**:187.

57. Plow M, Finlayson M, Motl RW, Bethoux F. Randomized controlled trial of a teleconference fatigue management plus physical activity intervention in adults with multiple sclerosis: rationale and research protocol. *BMC Neurol* 2012;**12**:122.
58. Saywell N, Vandal AC, Brown P, et al. Telerehabilitation to improve outcomes for people with stroke: study protocol for a randomised controlled trial. *Trials* 2012;**13**:233.
59. Zhang J, Song YL, Bai CX. MIOTIC study: A prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based internet of things in the management of patients with stable COPD. *International Journal of COPD* 2013;**8**:433–8.
60. Holden MK, Dyar TA, Dayan-Cimadoro L. Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. *IEEE Trans Neural Syst Rehabil Eng* 2007;**15**:36–42.
61. Heuser A, Kourtev H, Winter S, et al. Telerehabilitation using the Rutgers Master II glove following carpal tunnel release surgery: proof-of-concept. *IEEE Trans Neural Syst Rehabil Eng* 2007;**15**:43–9.
62. Cikajlo I, Rudolf M, Goljar N, Burger H and Matjacic Z. Telerehabilitation using virtual reality task can improve balance in patients with stroke. *Disability and rehabilitation*: 13–8 (2012).
63. Cox NS, Alison JA, Holland AE. Interventions for promoting physical activity in people with cystic fibrosis. *Cochrane Database Syst Rev* 2013;**12**:CD009448.
64. Jehn M, Prescher S, Koehler K, et al. Tele-accelerometry as a novel technique for assessing functional status in patients with heart failure: feasibility, reliability and patient safety. *Int J Cardiol* 2013;**168**:4723–8.
65. Scalvini S, Zanelli E, Comini L, et al. Home-based versus in-hospital cardiac rehabilitation after cardiac surgery: a non-randomized controlled study. *Phys Ther* 2013;**93**:1073–83.
66. Yuen HK. Effect of a home telecare program on oral health among adults with tetraplegia: a pilot study. *Spinal Cord* 2013;**51**:477–81.
67. Kowalczewski J, Chong SL, Galea M, Prochazka A. In-Home Tele-Rehabilitation Improves Tetraplegic Hand Function. *Neurorehabilitation and Neural Repair* 2011;**25**:412–22.
68. Sanford JA, Griffiths PC, Richardson P, Hargraves K, Butterfield T, Hoenig H. The effects of in-home rehabilitation on task self-efficacy in mobility-impaired adults: A randomized clinical trial. *Journal of the American Geriatrics Society* 2006;**54**:1641–8.
69. Lum PS, Taub E, Schwandt D, Postman M, Hardin P, Uswatte G. Automated Constraint-Induced Therapy Extension (AutoCITE) for movement deficits after stroke. *J Rehabil Res Dev* 2004;**41**:249–58.
70. Deng H, Durfee WK, Nuckley DJ, et al. Complex versus simple ankle movement training in stroke using telerehabilitation: a randomized controlled trial. *Phys Ther* 2012;**92**:197–209.
71. Kuttuva M, Boian R, Merians A, et al. The Rutgers Arm, a rehabilitation system in virtual reality: a pilot study. *Cyberpsychol Behav* 2006;**9**:148–51.
72. Finlayson M. Pilot study of an energy conservation education program delivered by telephone conference call to people with multiple sclerosis. *NeuroRehabilitation* 2005;**20**:267–77.
73. Page SJ, Levine P. Modified constraint-induced therapy extension: using remote technologies to improve function. *Arch Phys Med Rehabil* 2007;**88**:922–7.
74. Burkow TM, Vognild LK, Ostengen G, et al. Internet-enabled pulmonary rehabilitation and diabetes education in group settings at home: a preliminary study of patient acceptability. *BMC Med Inform Decis Mak* 2013;**13**:33.
75. Langan J, Delave K, Phillips L, Pangilinan P, Brown SH. Home-based telerehabilitation shows improved upper limb function in adults with chronic stroke: a pilot study. *J Rehabil Med* 2013;**45**:217–20.
76. Barnason S, Zimmerman L, Schulz P, Tu C. Influence of an early recovery telehealth intervention on physical activity and functioning after coronary artery bypass surgery among older adults with high disease burden. *Heart and Lung: Journal of Acute and Critical Care* 2009;**38**:459–68.
77. Ortiz-Gutierrez R, Cano-de-la-Cuerda R, Galan-Del-Rio F, Alguacil-Diego IM, Palacios-Cena D and Miangolarra-Page JC. A telerehabilitation program improves postural control in multiple sclerosis patients: a spanish preliminary study: (2013).
78. Russell TG, Buttrum P, Wootton R, Jull GA. Low-bandwidth telerehabilitation for patients who have undergone total knee replacement: preliminary results. *J Telemed Telecare* 2003;**9**(Suppl 2): S44–7.
79. Forducey PG, Glueckauf RL, Bergquist TF, Maheu MM, Yutsis M. Telehealth for persons with severe functional disabilities and their caregivers: facilitating self-care management in the home setting. *Psychol Serv* 2012;**9**:144–62.
80. Barnason S, Zimmerman L, Nieveen J, et al. Influence of a symptom management telehealth intervention on older adults' early recovery outcomes after coronary artery bypass surgery. *Heart and Lung: Journal of Acute and Critical Care* 2009;**38**:364–76.
81. Dallolio L, Menarini M, China S, et al. Functional and Clinical Outcomes of Telemedicine in Patients With Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation* 2008;**89**:2332–41.
82. Furber S, Butler L, Phongsavan P, Mark A, Bauman A. Randomised controlled trial of a pedometer-based telephone intervention to increase physical activity among cardiac patients not attending cardiac rehabilitation. *Patient Education and Counseling* 2010;**80**:212–8.
83. Hermens H, Huijgen B, Giacomozzi C, et al. Clinical assessment of the HELLODOC tele-rehabilitation service. *Ann Ist Super Sanita* 2008;**44**:154–63.
84. Huijgen BC, Vollenbroek-Hutten MM, Zampolini M, et al. Feasibility of a home-based telerehabilitation system compared to usual care: arm/hand function in patients with stroke, traumatic brain injury and multiple sclerosis. *J Telemed Telecare* 2008;**14**:249–56.
85. Russell TG, Buttrum P, Wootton R, Jull GA. Internet-based outpatient telerehabilitation for patients following total knee arthroplasty: a randomized controlled trial. *J Bone Joint Surg Am* 2011;**93**:113–20.
86. Chumbler NR, Quigley P, Li X, Morey M, Rose D, Sanford J. Effects of telerehabilitation on physical function and disability for stroke patients. *Stroke; a Journal of Cerebral Circulation* 2012;**43**(8): 2168–74.
87. Piqueras M, Marco E, Coll M, et al. Effectiveness of an interactive virtual telerehabilitation system in patients after

total knee arthoplasty: a randomized controlled trial. *J Rehabil Med* 2013;**45**:392–6.
88. Gutierrez RO, Galan Del Rio F, Cano de la C, Alguacil Diego IM, Gonzalez RA and Page JC. A telerehabilitation program by virtual reality-video games improves balance and postural control in multiple sclerosis patients: (2013).
89. Piron L, Turolla A, Agostini M, et al. Exercises for paretic upper limb after stroke: A combined virtual-reality and telemedicine approach. *Journal of Rehabilitation Medicine* 2009;**41**:1016–20.
90. Russell TG, Buttrum P, Wootton R, Jull GA. Internet-based outpatient telerehabilitation for patients following total knee arthroplasty: A randomized controlled trial. *Journal of Bone and Joint Surgery - Series A* 2011;**93**:113–20.
91. Larsen T. Evidence on the Efficacy of Integrated Care. *Handbook of Research on Information Technology Management and Clinical Data Administration in Healthcare*. IGI Global, 2009, p. 230–46.
92. Cheeran B, Cohen L, Dobkin B, et al. The future of restorative neurosciences in stroke: driving the translational research pipeline from basic science to rehabilitation of people after stroke. *Neurorehabil Neural Repair* 2009;**23**:97–107.
93. Page SJ, Gater DR, Bach YRP. Reconsidering the motor recovery plateau in stroke rehabilitation. *Arch Phys Med Rehabil* 2004;**85**:1377–81.
94. Wakeford L, Wittman PP, White MW, Schmeler MR. Telerehabilitation position paper. *Am J Occup Ther* 2005;**59**:656–60.
95. Brennan DM, Tindall L, Theodoros D, et al. A blueprint for telerehabilitation guidelines–October 2010. *Telemed J E Health* 2011;**17**:662–5.

Appendix 1. Electronic searches

MEDLINE search strategy (the search strategy uses MeSH terms unless indicated otherwise):

Set A terms (Combined by OR)
telerehabilitat*
"tele rehabilitation"
Telemedicine (and textword variations)
Telehealth (and textword variations)
"tele health"

Set B terms (Combined by OR)
Telemedicine

Set C (Combined by OR)
"remote consultation"
Telepathology (and textword variations)

Set D (Combined by OR)
random*
"meta analysis"
trial*
MEDLINE Search sets are:

1. (A OR B) OR C. Limits: Humans, Clinical Trial, Meta-Analysis, Randomized Controlled Trial
2. A OR C
3. 2 AND D. Limits: published in the last 60 days
4. 3 AND D

EMBASE search strategy:

1. telemedicine:ab,ti AND [humans]/lim AND [embase]/lim
2. 'telemedicine'/exp AND [humans]/lim AND [embase]/lim AND [medline]/lim
3. 'remote consultation':ab,ti AND [humans]/lim AND [embase]/lim
4. telerehabilitation:ab,ti AND [humans]/lim AND [embase]/lim
5. telehealth:ab,ti AND [humans]/lim AND [embase]/lim
6. telepathology:ab,ti AND [humans]/lim AND [embase]/lim
7. 'tele rehabilitation':ab,ti AND [humans]/lim AND [embase]/lim
8. 'tele health':ab,ti AND [humans]/lim AND [embase]/lim
9. 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8
10. 9 AND ([controlled clinical trial]/lim OR [meta analysis]/lim OR [randomized controlled trial]/lim) AND [humans]/lim AND [embase]/lim

THE COCHRANE LIBRARY – CLINICAL TRIALS DATABASE

Set A (Combined by OR)
telerehabilitat*
"tele rehabilitation"
Telemedicine
Telehealth
"tele health"

Set B (Combined by OR)
"remote consultation"
Telepathology

THE COCHRANE LIBRARY – CLINICAL TRIALS DATABASE Search Sets

1. A OR B
2. 1 AND NOT PUBMED
3. 2 AND NOT EMBASE

SEARCHING OTHER RESOURCES

The issues not available online from Journal of Telemedicine and Telecare (from Vol 1, 1995 to Vol 5, 1999) were hand searched. Letters were sent to authors or institutions to request information about studies reported as ongoing at the time of review or in case of poor reporting.