World Journal of Clinical Cases

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DOI: 10.12998/wjcc.v2.i8.316

World J Clin Cases 2014 August 16; 2(8): 316-326
ISSN 2307-8960 (online)

REVIEW

Progress in sensorimotor rehabilitative physical therapy programs for stroke patients

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Received: January 2, 2014 Revised: May 15, 2014
Accepted: July 12, 2014
Published online: August 16, 2014

Abstract

Impaired motor and functional activity following stroke often has negative impacts on the patient, the family and society. The available rehabilitation programs for stroke patients are reviewed. Conventional rehabilitation strategies (Bobath, Brunnstrom, proprioception neuromuscular facilitation, motor relearning and function-based principles) are the mainstream tactics in clinical practices. Numerous advanced strategies for sensory-motor functional enhancement, including electrical stimulation, electromyographic biofeedback, constraint-induced movement therapy, robotics-aided systems, virtual reality, intermittent compression, partial body weight supported treadmill training and thermal stimulation, are being developed and incorporated into conventional rehabilitation programs. The concept of combining valuable rehabilitative procedures into "a training package", based on the patient's functional status during different recovery phases after stroke is proposed. Integrated sensorimotor rehabilitation programs with appropriate temporal arrangements might provide great functional benefits for stroke patients.

Key words: Stroke; Rehabilitation; Sensory stimulation; Thermal stimulation

Core tip: Rehabilitation strategies, including conventional interventions with an empirical basis and advanced interventions based on scientific evidence, are reviewed. The concept of a training package that is related to the severity of impairment and the phase of recovery from stroke is proposed to maximize the recovery of motor function after a stroke. The training package for therapists provides valuable suggestions for selecting from the available and suitable advanced rehabilitation methods as well as from the conventional rehabilitation methods.

Chen JC, Shaw FZ. Progress in sensorimotor rehabilitative physical therapy programs for stroke patients. *World J Clin Cases* 2014; 2(8): 316-326 Available from: URL: http://www.wjgnet.com/2307-8960/full/v2/i8/316.htm DOI: http://dx.doi.org/10.12998/wjcc.v2.i8.316

INTRODUCTION

Following stroke, more than half of the patients have moderate to severe deficits at admission, and their functional activities are often confined to the bedside or wheelchair[1,2]. The most commonly occurring deficits are hemiparesis, resulting in an immediate impairment to upper limb function[2-4], or the ability to stand, balance and walk[2,3,5]. These deficits not only limit the person's activities in the family and participation in society but pose a heavy physical burden on their relatives or caregivers[6]. Stroke patients recover their walking function to a certain degree after discharge from hospital. However, 50% or more of stroke patients are still frustrated by mild or severe deficits of their upper limb functions 6 mo poststroke[2-5]. Thus, facilitating the restoration of upper limb motor function and maximizing walking ability as early as possible after a stroke are generally priorities for stroke patients, their families and clinicians.

In the clinic, numerous rehabilitative approaches have been shown to promote functional motor recovery after stroke[7-14]. In general, repetitive sensory stimulation and mass motor or task practice facilitate neuroplasticity and brain reorganization in stroke patients, resulting in enhanced motor and functional recovery after stroke[13-17]. In this scenario, physical therapy that emphasizes sensory stimulation has gained increased prominence among modern rehabilitation strategies[13-16]. However, there has been no systematic review of sensorimotor rehabilitation programs according to the patient's status during different stroke rehabilitation phases (the acute, subacute and chronic phases). Due to the dynamic and complex process of stroke recovery (the patient's status and recovery phase)[10,11] and the methodological heterogeneity in various studies[7-10], it is difficult to draw a conclusion as to which programs are superior to others or which ones could be adopted for the entire rehabilitation process. In this article, we attempt to summarize all of the possible programs and introduce a schematic program that combines valuable treatments[9,11] into "a training package" to maximize the functional outcomes of stroke patients.

CATEGORIZATION OF STROKE REHABILITATION PROGRAMS

Regarding physical therapy for stroke patients, the rehabilitative programs can be categorized into two main groups according to the theoretical backgrounds of the clinical trials[7-14]: conventional and advanced rehabilitation programs.

Conventional rehabilitation programs address the effectiveness of treatment approaches based on neurophysiological, motor control and learning, or strengthening and functional principles. These programs are often called traditional physiotherapeutic "schools"[7-9,13,14]. The present study considered conventional rehabilitation programs to be the regular or standard therapies applied in clinical stroke rehabilitation. Conventional rehabilitation strategies are mostly based on clinical experiences and observations[18-24]. They were developed early and are usually applied for routine rehabilitation in the clinic.

Advanced rehabilitation programs emphasize the effectiveness of specific interventions based on neuroscientific evidence[7-14]. Because stroke patients must receive a reasonable level of rehabilitation in the hospital, conventional rehabilitation strategies are generally employed in the clinic. There is concern over incorporating advanced rehabilitation strategies with conventional rehabilitation strategies in the hospital due to ethical issues. In particular, in the case of acute and subacute stroke patients, the assessment for advanced rehabilitation yields two groups: a conventional + advanced rehabilitation group *vs* a conventional rehabilitation group. Only a few studies in chronic stroke patients have directly compared the advanced treatment with "dose-matched" conventional rehabilitation.

CONVENTIONAL REHABILITATION STRATEGIES

The conventional rehabilitation strategies for stroke include the Bobath (also called Neurodevelopmental Treatment)[14,18,19], Brunnstrom[20], proprioceptive neuromuscular facilitation (PNF)[21], motor relearning[22] and the functional or strengthening[7-9,13,14,23,24] approaches. Although these approaches are mostly based on empirical results rather than scientific evidence, they or their concepts are commonly adopted in clinical settings in the standard or routine rehabilitation programs for stroke patients to regain their motor functions[7-9,11-14].

In recent decades, several studies have shown the positive effects of these interventions on the recovery of motor functions after strokes[23-33]. Among these approaches, the Bobath treatment is widely used in Western countries[30-33]. Abnormal muscle tone and movement patterns, which generally lead to impaired postural control, are deemed the two major problems experienced by people with hemiplegia. Therefore, a major goal of the Bobath treatment[18,19] is to normalize the movement pattern and postural control (or tone) by handling the major joints of each body part of the patient, such as the neck, shoulder, hand, hip, knee and ankle. Recently, the Bobath treatment was re-defined as a problem-solving approach for the assessment and treatment of individuals with deficits in function, movement, and postural control caused by a central nervous system lesion. The goals in a given task are successfully met by identifying and analyzing problems in the movement components and the underlying impairments during functional activities and participation[19]. Incorporating appropriate inputs (visual, verbal, or tactile) also plays a vital role in Bobath training because the afferent inputs affect the motor performance[19]. The Bobath treatment should improve the efficiency of movement and generally facilitate the activities of everyday life.

The Brunnstrom approach[20] considers six hierarchical movement developmental stages, from flaccidity to normal movement-pattern control. The Brunnstrom treatment involves a reflex or limb synergistic movement, initially with cutaneous stimulation. Later, the appropriate inhibition of the synergy pattern and facilitation of the anti-synergy pattern are required to attain normal movement control and functional performance. Visual and somatic modalities are considered in the motor training using the Brunnstrom approach, which facilitates volitional movement and motor recovery for patients with moderate to severe strokes.

The PNF approach stresses stimulating proprioceptors in the muscles/joints of the affected limbs following stroke. The PNF procedures are often accompanied by verbal/visual and tactile feedback to facilitate muscle

Table 1 Summary of conventional rehabilitation therapies with an emphasis on sensory inputs and outcomes

Treatment	Sensory inputs	Rationale	Sensory outcome	Result[1]
Bobath	Visual, verbal and tactile	Neurophysiology concept (emphasis on selective movement and postural control by key points of the body, with problem-solving training)	None	UL (-), LL (-)
Brunnstrom	Visual and cutaneous	Neurophysiology (an ordered, predictable, stepwise progression from initial flaccidity to stereotypical synergy and then to normal patterns of voluntary movements)	None	NA
PNF	Visual, tactile, verbal and proprioceptive	Neurophysiology concept (through the stimulation or relaxation of muscle groups combined with various sensory inputs in response to specific movement patterns to promote functional movement)	None	NA
Motor relearning	Visual, tactile and auditory	Neuropsychology (Active practice of context-specific motor task with well-designed motor and sensory components)	None	NA [UL (-) and LL (-) motor control with 3 RCTs]

[1]Obtained from meta-analyses or systematic reviews. PNF: Proprioceptive neuromuscular facilitation; -: Not better than the control group; LL: Lower limb; UL: Upper limb; NA: Not available; RCT: Randomized clinical trial.

contraction and motor control in terms of many techniques, such as joint approximation, traction, irradiation or overflow. Therapists rebuild the movement and function of the limbs rendered paretic due to strokes by guiding a specific movement pattern (diagonal or spiral direction) for concomitant muscle contractions with reversal, stabilization, repetition or combination techniques. The motor control or movement pattern facilitated by the therapist follows a sequence of static/dynamic and assistive-active-resistant progressions for regaining motor control and enhancing the muscle strength of the paretic limbs of stroke patients. Verbal and vision inputs are also basic facilitative procedures used in this approach[21]. The facilitated progression due to the PNF procedures follows a hierarchical process from mobility to stability, then controlled mobility to skillful movement.

The motor relearning technique[22] emphasizes the active practice of context-specific motor tasks in a structured environment with appropriate feedback, manual guiding or verbal commands. Through this well-designed learning program, stroke patients progressively learn to perform the task-oriented functional activities well. In general, the motor relearning technique consists of the following four steps: (1) analysis of the task; (2) practicing the missing components of the task; (3) practicing the entire task; and (4) transferring the training to perform the task. This technique requires the patient to first understand the kinematics and kinetics of normal movement and then the patients can use the kinetic knowledge to practice various dynamic characteristics of the movements necessary to complete a task. The motor relearning technique recruits a single or several inputs (visual, verbal, or auditory) within a training program.

The functional and strengthening approaches, which are based on theories regarding motor control and learning, consist of bed mobility, sitting, transfers, sit-to-stand and gait[7-9,13]. Clinically, the therapists target the impairments in the neuromuscular or musculoskeletal system following stroke and provide practice or an experience leading to changes in the capability of producing skilled action. To reduce impairments and facilitate functioning, the therapists encourage the patients to practice purposeful or functional movement and postural adjustment by selective allocation of muscle tension across joint segments[7-9,13].

The aforementioned rehabilitation strategies are often used in a clinical setting for stroke patients, but the scientific evidence regarding these conventional rehabilitation methods remains limited. The functional outcomes of the Bobath and motor relearning approaches[25-27] were not significantly different throughout a 4-year follow-up[27], but the motor relearning treatment is seemly preferred for shortening the length of hospitalization of stroke patients during the acute phase. No significant difference was found in the functional outcomes of stroke patients given the Bobath, PNF, Brunnstrom and/or strengthening treatments[24,28,29]. Although the Bobath technique is more popular in Western countries[30,31], recent reviews indicated that the Bobath technique is not superior to the other approaches in general, including the outcomes regarding the sensorimotor control of upper and lower limbs, dexterity, mobility, the activities of daily living or the health-related quality of life[31-33]. Interestingly, a mixture of treatments combining different approaches may be more beneficial than receiving no treatment or a placebo control for lower limb functionality and postural control after strokes[8].

Table 1 summarizes the characteristics of the sensory inputs and outcomes, theoretical basis, and the results of the four conventional rehabilitative strategies. Due to the methodological heterogeneity in previous studies and the lack of well-designed larger investigations, the ideal and favorable training strategies among these conventional treatments for stroke rehabilitation are yet to be determined[19-23].

ADVANCED REHABILITATION STRATEGIES

Numerous advanced and novel rehabilitation treatments have been developed for patients in the acute, subacute or chronic phase of stroke, to facilitate and maximize their functional recovery[7-14]. Most of these techniques are based on neuroscientific evidence rather than pragmatism. For instance, neuroplasticity and brain reorganization in patients with good functional recovery from strokes have been demonstrated using functional brain imaging or other advanced neuro-technologies[8-11,15,16]. Compared to conventional rehabilitation treatments, more high-quality clinical trials concerning the advanced rehabilitation strategies have been reported in recent decades. In this study, several advanced rehabilitation techniques and their enhanced results compared with those of conventional rehabilitation treatment are summarized below.

ELECTRICAL STIMULATION

Electrical stimulation (ES) is a technique that was developed early and is widely applied to stroke rehabilitation as an adjunctive treatment[7-10,17,34-44]. Many aspects of ES, including transcutaneous electrical nerve stimulation (TENS)[34-38], functional electrical stimulation (FES) or neuromuscular electrical stimulation (NMES)[14-17,34,37-40,44], and electromyographic (EMG) biofeedback[41-43], have been used for different clinical purposes. TENS is generally applied for sensory stimulation (sensory threshold) or for selective muscle contraction (motor threshold) based on the patient's status[35-38]. In contrast, the intensities of the other three modalities are largely above the motor threshold[34,37-44]. ES primarily stimulates cutaneous receptors and proprioceptors and/or activates muscle contractions and joint movements, which can increase the cortical excitability of the somatosensory and/or motor areas. Long-lasting cortical plasticity occurs, accompanied by motor recovery, in stroke patients treated by ES[13-17,36]. ES is popularly used as an adjunct in clinical rehabilitations and has a positive effect on the range of motion, motor control, and muscle strength of the affected limbs and the gait speed of stroke patients[13-16,34-43]. The ES intensity with sensory threshold shows effects on motor outcomes[16,37]. In particular, ES combined with active training significantly improved the performance of both sensory and motor functions[34,36]. In addition, ES may also be beneficial in preventing secondary complications of stroke[39], such as shoulder pain, subluxation, spasticity and upper limb contracture.

The EMG biofeedback technique, another type of ES involving minimally active muscle contraction at the targeted joint, is also beneficial for the control of motor function or the muscle strength of the upper limb following stroke[41-43]. However, the EMG-triggered feedback causes little improvement in upper limb functionality[43]. The effect of the NMES with three periods of stimulation on the upper extremities of 66 stroke survivors with severe motor deficits was investigated[44]. However, the optimal effective parameters of ES are inconclusive[36,37]. The ES treatments used in all of the previous studies have been added to conventional rehabilitation programs to enhance motor-function recovery after a stroke[34-38,40-44].

ROBOTIC-AIDED SYSTEMS

The most advantageous feature of robotic-aided system is that it reduces the physical effort of handling patients using computer-assisted devices. Because the system can automatically set the duration and intensity of the paretic limb movement using either passive or active assistance, robotic-aided therapy allows patients to train independently with no therapist or with a supervising therapist[45,46]. The device may provide different optimized movement patterns to help moderate to severe stroke patients regain their motor functions. However, a robotic-aided system requires that the distal part of the limb (hand or foot) be fixed on the handle bar or footplate of the device during training.

At least five types of robotic-aided systems have been developed for upper limb rehabilitation after a stroke, including the MIT-MANUS, the InMotion shoulder-elbow robot, the ARM Guide, the mirror-image motion enabler, and the bi-manu-track[45-50]. Generally, the exercise protocols of a robotic therapy system for upper limb rehabilitation after a stroke focus on shoulder and elbow movement patterns and fixing the hand (or fingers) in the robotic handle bar[44-48]. The system guides a patient's paretic hand on a support board in front of the patient and tracks the movement of the robotic handle to the target on the computer screen to attain a goal-directed movement through simultaneous visual, auditory, and proprioceptive feedback. Robotic-aided therapy has demonstrated advantages for motor recovery but did not affect the daily functions of stroke patients[46]. However, when directly compared with matched intensive conventional rehabilitative techniques, the robot-assisted therapy showed no additional benefit for moderate to severe arm impairment in subacute stroke patients[47].

The Lokomat and Gait Trainer were recently developed as robotic-gait machines for lower limb rehabilitation following stroke and are intended to relieve the strenuous efforts of the therapists[51-53]. Although their effects were not significantly different compared with those of a similar dosage of treadmill training[51] or conventional therapy[52], using the robotic-gait machine is a feasible treatment for lower limb and gait rehabilitation[51-53]. Robotic-gait therapy combined with conventional therapy is more effective for gait performance than conventional therapy alone in patients with subacute stroke who have greater motor impairment[53]. A similar phenomenon regarding better improvement has been reported for using robotic-gait therapy combined with FES treatment[54].

The use of a robotic-aided system for stroke rehabilitation is rapidly growing. Recently, robotic-aided therapy combined with individual arm therapy (IAT) using a motor relearning approach was as effective as double sessions of IAT in terms of the restoration of upper limb motor functions[47]. Robot-assisted therapy during the training phase is more convenient than conventional rehabilitation therapy. However, the cost of the devices is still prohibitive for the average clinic[52].

PARTIAL BODY WEIGHT SUPPORTED TREADMILL TRAINING

Partial body weight supported treadmill training (PBWSTT) involves using a treadmill with body-weight support provided by a harness that is connected to an overhead support system, with coincidental proprioceptive stimulation and visual inflow during stepping. PBWSTT is a method used to treat walking impairments post-stroke. PBWSTT has been used for more than 20 years and is beneficial for the walking function of stroke patients[55-60]. Initially, the stroke subjects in most of the previous PBWSTT studies were independent or partially independent walkers and many of the studies were conducted using chronic stroke patients[55-57]. These studies reported a good outcome after the application of the PBWSTT. In contrast, the outcomes of early severe stroke patients or even patients after a 6-mo follow-up compared with those given conventional rehabilitation training are controversial[57,58]. In a large long-term follow-up study, the effects of PBWSTT were not superior to progressive exercise at home that was managed by a physical therapist[59]. The use of PBWSTT for walking rehabilitation of stroke patients slightly improved the walking velocity and walking endurance but not significantly compared with the effects of conventional rehabilitation[60]. Moreover, two (or even three) therapists and a strenuous effort are generally required during PBWSTT therapy. Thus, these factors could limit clinical therapists from initiating walking training on the treadmill to moderate to severe stroke patients in the acute phase.

VIRTUAL REALITY

Computerized virtual reality (VR), a type of human-computer interface technology, allows patients to interact with a multisensory simulated environment and to receive "real-time" feedback on their performance[61,62]. Visual and auditory feedback is crucial for instantaneous reactions to stimulation from the environment or the exercises. The feedback training incorporated with conventional rehabilitation treatment led to significant improvement of the upper arm functions of stroke patients[61,62].

VR applications can range from nonimmersive to fully immersive. Recently, a variety of nonimmersive video game systems developed by the entertainment industry have become available for home use. The home-based VR system is inexpensive and more accessible to clinicians and individuals. Among patients with acute strokes who were receiving conventional rehabilitation, the group receiving VR therapy using Wii games demonstrated better recovery of motor function than the recreational group[63]. Furthermore, VR therapy in conjunction with PBWSTT treatment is feasible and effective in improving patients' walking and balancing abilities post-stroke[64].

Although VR can enhance patients' motivation and compliance regarding rehabilitation and reduce their perception of exertion during activities, it is unable to replace actual sensory experiences, such as manipulating objects during normal daily activities. Sometimes, the VR system may cause symptoms of motion sickness, such as nausea, disorientation, dizziness, and headache, in a few patients during training[61]. A recent review[62] summarized the results of five randomized clinical trials (RCTs) and seven observational studies, concluding that large multicenter, well-designed randomized trials of VR therapy are required. However, the subjects enrolled in most VR studies have a moderate to mild status, which limits the apparatus to a selected group of stroke patients. The cost and complexity of VR devices and the supporting software may not be acceptable for all clinical centers.

INTERMITTENT COMPRESSION

The intermittent compression technique is a neurophysiological treatment. This treatment involves the stimulation of cutaneous and proprioceptive receptors by repeated movements. Previous randomized control trials have shown its beneficial effects on the sensory and motor functions of stroke patients in the acute[65] or chronic[66] phase. A significant enhancement was observed in subjects even at the 5-year follow-up[67]. However, heretofore, no further investigations have been conducted.

CONSTRAINT-INDUCED MOVEMENT THERAPY

Constraint-induced movement therapy (CIMT) is a revolutionary rehabilitation technique based on the "learned non-use" theory[68-73]. The concept of CIMT involves constraining the movements of the non-affected arm with a sling or mitten and forcing the paretic hand to practice using a task-orientated approach for most of the waking hours. Highly intensive and mass-repetitive practice using the affected arm is the major requirement for at least 2 wk of training. Two mechanisms underlying CIMT were proposed[71,73]: the "learned non-use" of the affected limb, which is often behaviorally reinforced, is reversed and the contralateral cortical area responsible for the movement of the affected limb is expanded due to repetitive forced use[69]. Although CIMT therapy has been proven to have a significant effect on the upper limb mobility following strokes[68-73], a minimal voluntary movement (wrist extension of at least 20 degrees and finger flexion of 10 degrees) at the beginning of treatment and during long-duration daily treatment is required for the application of this therapy. Thus, it is uncertain whether the CIMT approach is appropriate for patients with flaccidity or little volitional movement of their upper limbs during either the early or chronic phase of stroke and those with insufficient tolerance of the method. In the case of mild motor function in chronic stroke patients[71,73], CIMT therapy could act as a routine rehabilitation technique.

THERMAL STIMULATION

Thermal stimulation (TS) was first developed using alternative hot and cold stimulation. TS combined with conventional rehabilitation methods has been demonstrated to facilitate upper-limb motor function in acute stroke patients[74]. TS causes greater activation of the brain areas

Table 2 Comparison of the characteristics of sensory stimulation modalities and the rationales for recent advanced rehabilitation strategies and their outcomes

Treatment	Sensory modality	Rationale	Sensory outcome	Result[1]
Electrical stimulation	Proprioceptive and tactile	Neurophysiology/neuropsychology	Yes (+)	UL (+) for motor control, LL (+) for gait ability
Robotic therapy	Visual, auditory and proprioceptive	Neurophysiology/neuropsychology	None	UL (+) for motor control
Virtual reality	Visual and auditory	Neuropsychology	None	NA [UL (+/-) motor control with RCTs]
Intermittent compression	Tactile and proprioceptive	Neurophysiology	Yes (+)	NA [UL (+) motor control with RCTs]
CIMT	Visual and verbal	Neuropsychology	None	UL (+)
PBWSTT	Visual and proprioceptive	Neurophysiology/neuropsychology	None	LL (+) motor and gait function
Thermal stimulation	Hot and cold agent	Neurophysiology/neuropsychology	Yes (+)	NA [UL/LE (+) motor control with 5 RCTs]

[1]Obtained from meta-analyses or systematic reviews. CIMT: Constraint-induced movement therapy; PBWSTT: Partial body weight-supported treadmill training; +: Positive effect; -: No better than the control group; LL: Lower limb; UL: Upper limb; NA: Not available; RCT: Randomized clinical trial.

involved in tactile or mechanical stimulation, as shown in functional brain imaging studies of healthy subjects[75,76]. In RCTs, TS significantly improved several aspects of the upper- and lower-limb outcomes of acute and subacute stroke patients[74,77-80] when combined with standard rehabilitation therapy. Comparable enhancement was also observed and maintained in the lower-limb outcomes at the 3-mo follow-up but disappeared at the 6-mo follow-up[79]. The use of TS in rehabilitation not only provides sensory stimulation but also deploys the forced-use strategy to provoke volitional/reflexive motor activity. Neural plasticity may be a reason for the effect of TS in stroke patients. TS can be a low-cost, practicable intervention using home-made materials, such as a water pack. Thus, TS can easily be established as a generally popular home-care therapy. Table 2 summarizes the characteristics of the stimulation modalities used in recent rehabilitation programs.

A "TRAINING PACKAGE" CONCEPT FOR REAHBILITATION

Both conventional rehabilitation strategies and the recently developed advanced treatments mostly emphasized the motor functional outcomes and viewed various types of sensory stimulation (inputs) or feedback as crucial components in stroke rehabilitation[7,13-17,34-38,41-43,46,63,74]. A large number of robust large-scale studies of evidence-based treatments for stroke rehabilitation have been published in recent decades[7-11]. These studies provide evidence that advanced rehabilitation methods significantly enhance functional outcomes during particular phases of recovery from stroke. In addition to the significance of the advanced rehabilitation therapies, knowing the ideal and most powerful training strategies for recovery during the acute, subacute to chronic phases is very helpful to stroke patients and therapists. Before we describe the concept of an ideal training program (a training package), several perspectives need to be considered.

First, no clear evidence indicates that the recently developed rehabilitation therapy can replace any of the treatments based on physiotherapeutic "schools" that are generally viewed as the standard rehabilitation treatments for stroke. In general, most of the specific rehabilitation strategies have been adopted or added as supplementary methods by therapists to reinforce functional recovery after stroke. The significance of the advanced therapies, such as ES[37,38,42], robotic therapy[46], virtual reality therapy[62], PBWSTT[59,60], and CIMT[71,73], has been derived through meta-analysis of stroke patients in a particular phase. However, no large longitudinal study that integrated these advanced therapies to treat stroke patients throughout the entire rehabilitation process has been conducted.

Second, previous studies focused mostly on comparing the effect of specific treatments within a particular period following stroke, either in the acute/subacute or chronic phase. However, the progress of stroke recovery is dynamic and individualized, dependent on the nature of the injury, the patient's characteristics and other intrinsic or extrinsic factors[10,11]. Faced with the dynamic alteration of motor function, there is no evidence to support that any single intervention plays an important role in achieving the maximum benefit throughout an entire rehabilitation process, from acute to subacute to chronic status. Due to the diversity of the advanced treatments and the heterogeneous methodologies applied, previous meta-analyses or systematic review articles generally focused on the effect of a single specific treatment[9,14,36-38,42,46,60,62,71,73]. Thus, it is difficult to compare their performance in a time-related progression.

Third, very few studies have systematically evaluated the optimal intensity and/or duration of a specific intervention. Thus, it is unclear what the threshold of an effective "dose" of an intervention might be or how long an effective intervention should be applied. As a result, the intervention may cease before rehabilitation reaches a peak. Lastly, therapy in clinical practice is often provided for only a few weeks, generally 4 to 8 wk[9,14,31,36-38,42,46,60,62,73]. A therapy may fail to provide comprehensive progression in the intensity and task complexity because the optimal frequency and duration of treatment sessions are undetermined. Moreover, therapists often use the treatments either single or combined with other treatments in clinical practice according

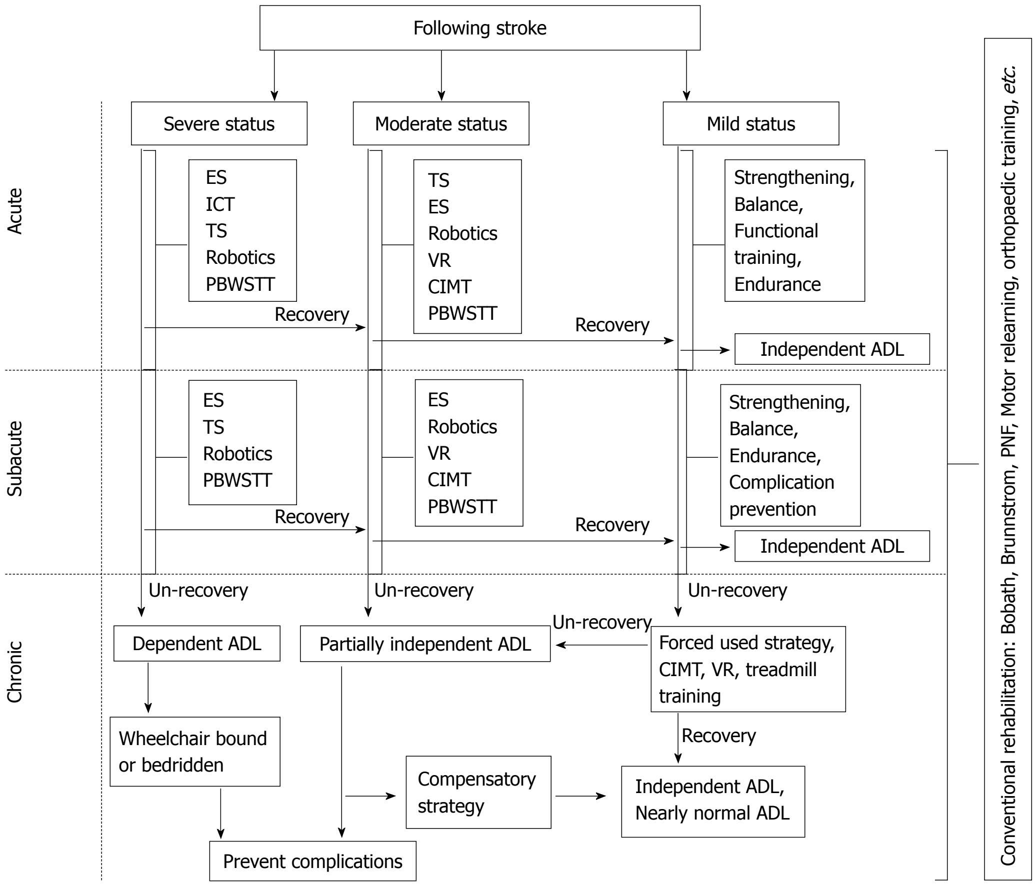

Figure 1 Schematic flowchart for selecting from the available rehabilitation strategies for stroke patients with impairments of various severity levels during different stroke phases. Functional recovery from a severe to moderate and mild condition after stroke is indicated by arrows with indications of the progression of recovery and unrecovery. Appropriate advanced rehabilitation technique(s) combined with conventional rehabilitation are selected to maximize the patient's functional recovery according to his/her initial motor function (mild, moderate or severe) in the clinic. ADLs: Activities of daily living; CIMT: Constraint induced movement therapy; ES: Electrical stimulation; PBWSTT: Partial body weight supported treadmill training; PNF: Proprioceptive neuromuscular facilitation; TS: Thermal stimulation.

to the patient's status and progress during the recovery phase. Therefore, customizing the available interventions during different recovery phases after stroke to meet the needs of the patient's current status to optimize the outcomes will be a major challenge for therapists.

A single or two rehabilitation approaches can be easily used in the clinic and home, and these strategies must be based on the individual's progression throughout the rehabilitation period. Combining valuable treatments is believed to be a good tactic for facilitating the restoration of functional mobility. It is generally believed that treatments could be given in a parallel or sequential way depending on the patient's recovery process and her/his functional status. Figure 1 shows a schematic diagram of the available techniques that are suggested for patients with different functional status during the three stroke phases. Based on the available evidence described above, the appropriate advanced intervention combined with a conventional rehabilitation treatment has been summarized for stroke patients with impairments of different severities. Functional progression is indicated by arrows in terms of the outcome, *i.e.*, recovery or unrecovery. The therapist can easily select the appropriate strategies to maximize the functional outcome of stroke patients.

For instance, if a patient shows little or no voluntary movement of the paretic limb (severe status) during the early poststroke stage, rehabilitation through task-oriented training is often difficult to apply[50-57]. Most of newly developed therapies, which require a minimal motor ability, cannot be utilized during the early phase of recovery of stroke patients[40,49-50,53-58]. ES[35-37], TS[74,78-79] and robotics-aided treatments[44,46,48] provide significant improvement in several aspects of motor or functional activities, particularly for those in the initial phase of recovery from moderate to severe strokes who show little or no voluntary movement. Thus, these techniques could be chosen to treat or activate motor activity in the paretic limbs. Until the patient' condition has progressed to a moderate or mild status, alternative interventions, such as VR, CIMT or PBWSTT, which combine strengthening and functional training strategies, can improve the outcome. From a practical perspective, the training package schematic shown in Figure 1 provides selective strategies for the initial phase of recovery to the subsequent recovery process for stroke patients with a different severity status. Although the various interventions are categorized according to the severity status, an optimal rehabilitation program (the ideal training package) can be individualized and needs to be further investigated.

An appropriate protocol for a selected group of patients plays an important role in terms of cost-effectiveness, limiting the period of hospitalization and minimizing the labor of the therapist during the early phase of stroke recovery. For example, in terms of a "training package", when therapists need to decide the clinical plan for the upper limb rehabilitation of acute stroke patients with a moderate to severe status during the initial stage, the TS technique would be the choice that facilitates active movement cost-effectively as early as possible. When a certain degree of voluntary movement is elicited in the stroke patient, the therapist can apply other suitable techniques, such as CIMT or forced use with a task-oriented approach. Ideally, a protocol combining several rehabilitation strategies at the right time, as "a training package", could maximize the patient's progress during recovery. Although we propose a reasonable strategy for planning a rehabilitation roadmap based on the available evidence for a particular status of stroke, the ideal training package for the progression of a stroke patient remains to be determined.

CONCLUSION

Rehabilitation is a long process for a stroke patient. How to choose the appropriate route(s) in a complex roadmap for stroke patients whose status differs during the phases of their recovery is always a great challenge to the clinician, patient and family. Conventional rehabilitation therapies (including the Bobath, PNF, motor relearning and Brunnstrom techniques, either singly or combined) are the regular or routine treatments applied in stroke rehabilitation units. Several advanced rehabilitation strategies with a strong evidence basis have been developed and are summarized here. According to the patient's mobility status and recovery phase, the appropriate advanced rehabilitation therapy combined with conventional rehabilitation treatment comprise a training package. This training package may provide suggestion for therapists to maximize the improvement of stroke patients in the right timeframe. To further validate the usefulness of the training package approach, longitudinal or serial studies of the outcomes of selected and combined therapies are important.

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P- Reviewer: Cui L, Lai SL **S- Editor**: Song XX
L- Editor: Wang TQ **E- Editor**: Lu YJ

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