




Motor rehabilitation after stroke: European Stroke Organisation (ESO) consensus-based definition and guiding framework

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Abstract

Purpose: To propose a consensus-based definition and framework for motor rehabilitation after stroke.

Methods: An expert European working group reviewed the literature, attaining internal consensus after external feedback.

Findings: Motor rehabilitation is defined as a process that engages people with stroke to benefit their motor function, activity capacity and performance in daily life. It is necessary for people with residual motor disability whose goal is to enhance their functioning, independence and participation. Motor rehabilitation operates through learning- and use-dependent mechanisms. The trajectory of motor recovery varies across patients and stages of recovery. Early behavioral

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restitution of motor function depends on spontaneous biological mechanisms. Further improvements in activities of daily living are achieved by compensations. Motor rehabilitation is guided by regular assessment of motor function and activity using consensus-based measures, including patient-reported outcomes. Results are discussed with the patient and their carers to set personal goals. During motor rehabilitation patients learn to optimize and adapt their motor, sensory and cognitive functioning through appropriately dosed repetitive, goal-oriented, progressive, task- and context-specific training. Motor rehabilitation supports people with stroke to maximize health, well-being and quality of life. The framework describes the International Classification of Functioning, Disability and Health in the context of stroke, describes neurobiological mechanisms of behavioral restitution and compensation, and summarizes recommendations for clinical assessment, prediction tools, and motor interventions with strong recommendations from clinical practice guidelines (2016–2022).

Conclusions: This definition and framework may guide clinical educators, inform clinicians on current recommendations and guidelines, and identify gaps in the evidence base.

Keywords

Review, motor rehabilitation, motor recovery, assessment, prediction, intervention

Introduction

Stroke is the third leading cause of death and disability worldwide¹ and a leading cause of adult disability in Europe.² Forecasts for Europe from 2017 to 2047 predict a 17% decrease in stroke mortality, but a 27% increase in stroke prevalence.² These trends are expected to increase demand for stroke rehabilitation services.

The European Stroke Organisation (ESO) has released a European Stroke Action Plan (ESAP)³ and defined 30 targets and 72 research priorities within seven domains to improve stroke services. One of these domains is stroke rehabilitation for improving management, outcome and quality of life after stroke in 2030.³ Rehabilitation was defined following the WHO as “a set of measures that assist individuals, who experience or are likely to experience disability, to achieve and maintain optimal functioning in interaction with their environments.”⁴ This general definition encompasses several neurological domains such as motor function, cognition and communication, but specific principles of motor rehabilitation were not addressed.

This article presents a definition of “motor rehabilitation” developed by expert consensus. The agreed definition is supported by a framework that synthesizes key literature to provide a state-of-the-art overview of the stroke motor rehabilitation domain. This framework is intended to guide educators who train stroke rehabilitation clinicians, to update clinicians about current recommendations and guidelines, and to enable researchers to identify gaps in the evidence base.

Development of a consensus-based definition of motor rehabilitation after stroke

The ESO Guideline Board invited a panel of 16 experts to collaborate on a definition of post-stroke motor rehabilitation, using standard ESO operating procedures.⁵ The panel

engaged in a three-round process. The first round consisted of online meetings in April and May 2022 where the panel agreed to structure the definition as a paragraph. A first draft of the definition paragraph was presented to panelists through an online survey, and panelists had the options to agree, suggest changes, request additional elements, or disagree with the paragraph. Results were collated (available from GV) and presented to the expert panel for discussion and revision at the end of June 2022. A second-round survey was held in July–August 2022, and panelists could agree or disagree with each part of the definition. A 75% agreement threshold was defined a priori for acceptance of each part of the definition, similar to formal Delphi processes.^{6,7} Results were collated (also available from GV) and presented in September to the expert panel, with further discussion and fine-tuning. The topic sentence at the beginning of the definition paragraph reached 91.7% agreement. The next three supporting sentences provide further explanation of the concept and reached 75%, 91.7%, and 81.8% agreement, respectively. The final concluding sentence reached 91.7% agreement. Along with the definition, a separate glossary related to motor rehabilitation was compiled (Box 1).

Expert panel members presented the agreed definition to a convenience sample of clinicians working in stroke rehabilitation through in-person and online consultation. Feedback was collated (available from GV) and discussed by the expert group in December 2022 with fine-tuning of the definition. The final agreed definition on motor rehabilitation after stroke is presented in Box 2. The definition was also discussed with two persons with lived experience of stroke, who confirmed that all elements of the definition were highly relevant and important for motor rehabilitation. They emphasized including maximizing health, well-being and quality of life, and the need to communicate that patients can improve, even long-term after stroke.

The definition paragraph describes key concepts. Further details are needed when using the definition in education,

Box 1. Glossary and definitions.

Behavioral adaptation: occurs when the movement or task is executed with the impaired body part but an alternative atypical movement pattern is used. Behavioral adaptation results in deviating quality of movement compared to non-disabled individuals.^{a,b}

Behavioral compensation: occurs as adaptation, in which the impaired body part is used in an atypical way to accomplish a movement or a motor task; or as substitution, in which different atypical body part(s) or body segment(s) are used to accomplish a task.^{a,b}

Behavioral restitution: a return toward more normal patterns of motor control with the impaired body part(s) as seen in pre-stroke state.^{a,b}

International Classification of Functioning, Disability and Health (ICF) terminology^c

- Body functions: the physiological functions of body systems.
- Body structures: anatomical parts of the body such as organs, limbs and their components.
- Impairments: problems (the negative term) in body functions and structures.
- Activities: the execution of a task(s) or action(s).
- Activity limitations: difficulties (the negative term) in executing tasks and activities.
- Activity capacity: relates to what an individual can do in a “standardized” environment.
- Activity performance: what the person actually does in his or her “current” (usual) environment.
- Participation: involvement in a life situation.
- Participation restriction: problems (the negative term) an individual may experience in involvement in life situations.
- Functioning: an umbrella term for body function, body structures, activities and participation. It denotes the positive or neutral aspects of the interaction between a person’s health condition(s) and that individual’s contextual factors (environmental and personal factors).
- Disability: an umbrella term for impairments, activity limitations and participation restrictions. It denotes the negative aspects of the interaction between a person’s health condition(s) and that individual’s contextual factors (environmental and personal factors).

Motor control: the process whereby the central nervous system produces purposeful coordinated movements to interact with the rest of the body and the environment.^d

Motor function: body functions related to muscle force and endurance, control over and coordination of voluntary movements, and movement patterns associated with walking, running or other whole body movements.^c

Motor learning: the changes, associated with practice or experience, in internal processes, that determine a person’s capability for producing a motor skill.^e

Motor recovery: the extent to which motor functions and activities have returned to their pre-stroke state.^a

Motor skill: a skill for which the primary determinant of success is the quality of movement that the performer produces.^e

Motor skill acquisition: the processes by which an individual acquires the ability to identify an appropriate movement goal given a particular task context, select the correct action given a sensory stimulus and/or the current state of the body and the world, and execute that action with accuracy and precision.^f

Multidisciplinary rehabilitation: defined by the World Health Organization (WHO) as the coordinated delivery of multidimensional rehabilitation intervention provided by two or more disciplines (such as nursing, physiotherapy, occupational therapy, social work, psychology and other allied health), in conjunction with medical professionals (rehabilitation physician, neurologist; oncologist; palliative physician), which aims to improve patient symptoms and maximize functional independence and participation (social integration) using a holistic biopsychosocial model, as defined by the ICF.^c

Neural plasticity: structural or functional changes (or both) within neurons that affect the connectivity of neurons with each other in a network serving a function. These changes are usually in response to a change in neuronal input or firing patterns induced by this input, such as during learning (use- and experience-dependent) or after injury.^g

Phases of stroke recovery:^a

- Hyperacute from 0 to 24 h post stroke onset
- Acute between 1 and 7 days
- Early subacute between 7 days and 3 months
- Late subacute between 3 and 6 months
- Chronic phase beyond 6 months post stroke

Spontaneous neurological recovery: improvement in function and activities that is independent of specific targeted treatment and occurs within a restricted time-window of the first 3 months after stroke onset. It is considered an endogenous repair process that presumably relies on residual intact neural architecture as a template for reorganization.^{g,h}

Quality of movement (QoM): operationally defined by comparing an individual’s motor task execution to a reference population of non-disabled age-matched individuals. The closer the movement matches to those seen in non-disabled individuals, the better the quality of their movement.ⁱ

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Box 2. Agreed, expert-based definition of motor rehabilitation after stroke.

Motor rehabilitation is a process that engages people with stroke in order to benefit their motor function, activity capacity and performance in daily life. It is necessary for all people with residual motor disability whose goal is to enhance their functioning, independence and participation.

Motor rehabilitation strives to reduce motor impairments and improve functioning in activities through learning- and use-dependent mechanisms. The trajectory of motor and functional recovery varies between patients and stages of recovery. At early stages, behavioral restitution of motor function depends on the underlying mechanisms of spontaneous neurological recovery. At later stages, further functional improvements can be achieved by compensations.

Motor rehabilitation is guided by regular assessment of motor function and activity using consensus-based measures, including patient-reported outcomes. Results are discussed with the patient and their carers in order to set personal goals.

The core element of motor rehabilitation incorporates principles of motor control in which patients learn to optimize and adapt their motor, sensory and cognitive functioning through appropriately dosed, repetitive, goal-oriented, progressive, task- and context-specific training.

Motor rehabilitation supports people with stroke to maximize health, well-being and quality of life.

clinical practice and research. We addressed this by developing a framework that elaborates on each component of the definition. This framework is presented below to contextualize the motor rehabilitation definition.

Motor rehabilitation after stroke framework

Overarching concept: The International Classification of Functioning, Disability and Health

The first sentence of the definition positions it with respect to the International Classification of Functioning, Disability and Health (ICF). The ICF conceptualizes interactions between body functions and structures, activities, and participation in relation to environmental and personal factors (Figure 1).⁸ Body functions can be impaired, activities can be limited, and participation can be restricted. Assessments in the body functions domain evaluate physiological functions of body systems, such as muscle strength and synergies, coordination, pain, and muscle tone. Assessments in the activity domain evaluate the execution of tasks such as reaching and grasping, self-care, mobility and walking. The primary goal for many patients is to return to participation in their home environment and life roles. Therefore, assessments in the participation domain evaluate involvement in everyday life situations such as shopping, working, and socializing. Capacity and performance are two constructs used in the activity and participation domains. Capacity relates to what an individual can do in a standardized environment or test situation, while performance relates to what a person actually does in their habitual environment.⁸ Environmental and personal factors can be barriers or facilitators of the person's functioning. Figure 1 illustrates the ICF in the context of motor rehabilitation after stroke.

Regaining motor function is critical for independence in activities of daily living,⁹ which is associated with satisfactory quality of life. The concept of "Quality of Life" was not originally part of the ICF framework, however it has been defined by the World Health Organization¹⁰ Quality of Life Group as an "individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns" (p. 11). It can be thought of as an overarching concept related to all domains of the ICF.¹¹

It is important to note that the components of the ICF are interrelated in a non-linear way. An impairment in body function, such as leg muscle weakness, does not necessarily produce a limitation in walking or a restriction in participation. Furthermore, motor functions are closely related to and influenced by other body functions such as sensation, pain, cognition, mood and fatigue. All these aspects of functioning need to be considered in post-stroke motor rehabilitation.

Motor recovery

The second section of the definition reflects the biology of recovery and distinguishes between improvements at early versus later stages after stroke. Motor recovery probably occurs through a combination of spontaneous biological processes and "use-dependent" processes that include motor learning and skill acquisition.^{12,13} The interactions between spontaneous biological processes at molecular, cellular, and physiological levels and the mechanisms of learning in the first months post-stroke are still poorly understood.¹³

Most stroke rehabilitation studies use the term "recovery" as a general expression of "change" or "improvement," without distinguishing between behavioral restitution or compensation.^{12,14,15} In general, the term "motor recovery" indicates restitution of behavior after stroke, where

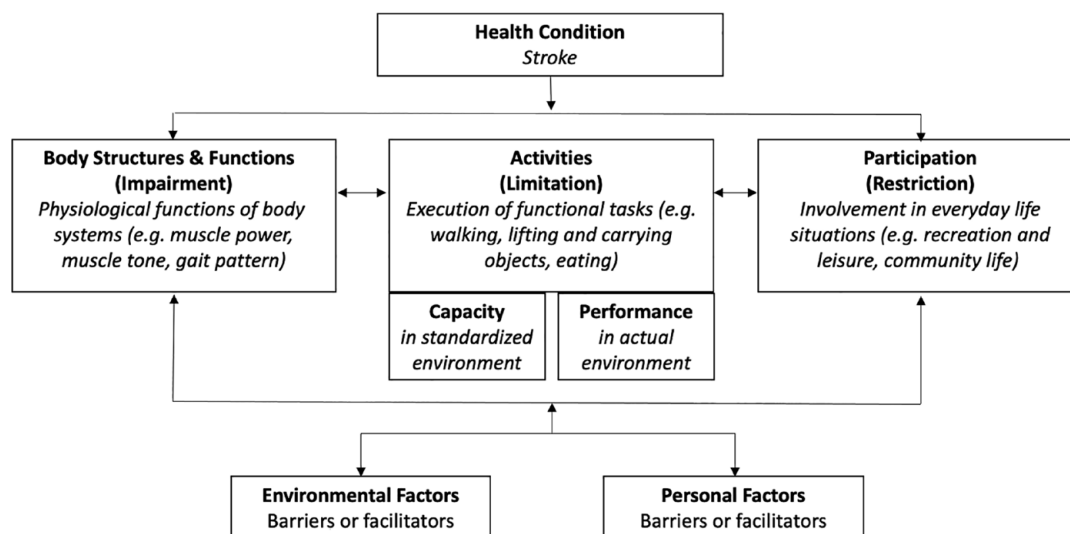


Figure 1. The international classification of functioning, disability and health.⁸

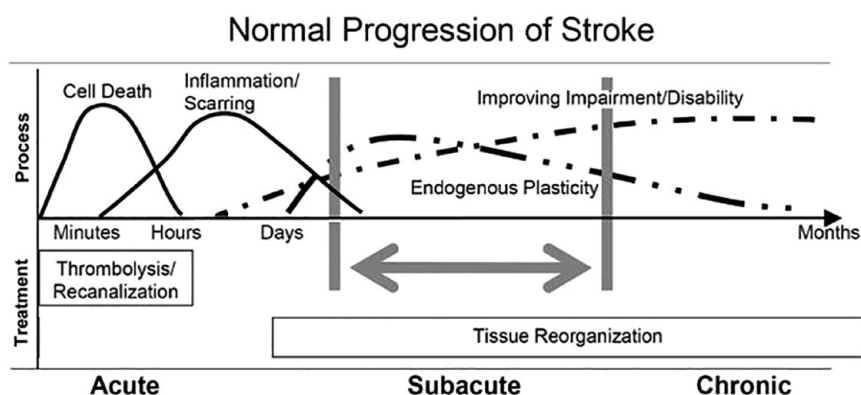


Figure 2. Patterns, processes and treatment opportunities post-stroke (adapted from Dobkin and Carmichael,²⁸ used with permission).

movements or tasks are performed as they were before stroke. This “true recovery” is thought to reflect spontaneous biological recovery processes occurring during the initial days and weeks after stroke. In contrast, the term “compensation” encompasses performing movements or tasks with atypical movement patterns at the expense of movement quality, or through performing tasks with a different limb altogether. Adaptation and compensation are thought to result from motor learning processes that can continue indefinitely after stroke.

Findings from several longitudinal studies show that for most stroke patients spontaneous neurological recovery and behavioral restitution follow a logistic pattern that plateaus within the first 10 weeks post-stroke, regardless of their age or the type and amount of therapy they complete (Figure 2).^{9,16–18} Spontaneous neurological recovery is observed for the upper limb^{19–21} and lower limb,^{22,23} as well as somatosensory,^{24,25} visuospatial,²⁶ and language functions.²⁷ Patients with initially mild to

moderate motor impairment typically exhibit early spontaneous neurological recovery of upper and lower limb motor functions. Some patients with initially more severe motor impairment can also exhibit early or slightly delayed spontaneous recovery,²¹ while others remain severely impaired.^{17,20}

Spontaneous neurological recovery is initiated by the cascade of neurochemical processes resulting from focal ischemic brain injury. These involve bio-energetic failure leading to excitotoxicity and oxidative stress, mitochondrial failure, and ultimately to apoptosis and cell death.²⁹ These pathologic processes start within minutes after stroke onset,³⁰ expand quickly within hours, and may continue for days even if perfusion is restored.²⁹ Ultimately, the cascade of pathophysiological processes leads to permanent loss of neurons, microglia, astrocytes and endothelial cells in the infarcted area that includes damage to the blood-brain barrier as well as transsynaptic degeneration in remote, anatomically connected brain areas.¹⁶

The mechanisms responsible for behavioral restitution are less well understood.^{13,31,32} The following time-restricted, overlapping processes contribute to behavioral restitution and compensation post-stroke.

1. Autoregulation of vascular collaterals can compensate for focal hypoperfusion and support the survival of penumbral tissue. A larger number of collaterals is associated with smaller final infarct volumes, faster and more extensive spontaneous neurological recovery in the first week post-stroke³³ and ultimately better outcomes.³⁴
2. Neuronal plasticity in perilesional areas is enhanced by a cascade of post-ischemic inflammation processes in the initial days and weeks post-stroke. At a cellular level, neuronal networks are (re)modeled by competition and selection in response to training and experience.¹³ The sensitivity of cortical mapping with non-invasive serial neuroimaging³⁵ or transcranial magnetic stimulation^{36,37} techniques to these neuronal plasticity mechanisms is unclear.
3. Gradual peripheral effects can influence and constrain behavioral restitution and force patients to compensate for their motor performance after stroke. These include neural components such as spasticity, and mechanical effects such as loss of muscle volume and serial sarcomere number^{38,39} altering the length-tension relationship,⁴⁰ as well as higher passive stiffness in tendons and soft tissues.^{41,42}

Behavioral restitution is driven by poorly understood mechanisms of spontaneous neurological recovery and plateau within 10 weeks after stroke.⁴³ Unfortunately, there is currently insufficient evidence in humans that rehabilitation therapies interact with the biological mechanisms responsible for behavioral restitution.^{17,20} Fine-grained biomechanical measures of movement quality indicate that therapy-induced improvements are mainly adaptive, as patients learn to optimize the use of their limbs to accomplish a standardized task. For example, hand transport and orientation for grasping with the paretic upper limb is characterized by increased muscle synergies between shoulder abduction and elbow flexion.^{44,45} To compensate for the limitations imposed by these muscle synergies, patients learn to flex and rotate their trunk to expand their limited workspace and improve hand orientation.^{43,44,46} Similarly, faster walking speeds are achieved via compensation with the less-affected side post-stroke, and without significant improvements in paretic intralimb coordination.⁴⁷ Overall, the evidence indicates that improvements at the level of activities result from a combination of behavioral restitution of impaired body functions occurring mainly in the first 10 weeks post-stroke,¹⁷ as well as learning to deal with residual impairments by using compensatory movement

strategies. These findings support the growing point of view that motor rehabilitation interventions mainly help patients learn to *optimize* their performance by *adaptation* and compensation through appropriately dosed, repetitive, goal-oriented, progressive, task- and context-specific training.⁴⁸

Assessment of motor function and activity

The third section of the definition is supported by widely recommended motor assessments and prediction tools. Repeated motor assessments, preferably at specific time-points, result in a better understanding of recovery. International consensus recommends early assessment within 1 week, followed by assessments at 4 weeks, and 3 and 6 months after stroke, as these times relate to key transitions in the biological processes underlying recovery.¹⁶ Standardized assessments at specific times post-stroke provide transparency in stroke care pathways and allow comparison of stroke rehabilitation outcomes at the national, regional and global level. Aggregated standardized assessment data are also expected to reveal which interventions are effective in clinical practice, including information about dose, timing, and setting.⁴⁹

Recent evidence- and consensus-based recommendations for motor assessments after stroke have several common features and are summarized in Table 1. In clinical practice, motor assessment should be performed at least before and after rehabilitation programs, using standardized measures with sound psychometric properties and established validity, reliability, responsiveness, and interpretability.⁴⁹⁻⁵¹ The Fugl-Meyer motor assessment, Action Research Arm Test, and 10m walk test are commonly recommended for both clinical practice and research. Standardized measurement of upper limb movement quality using kinematic methods has also been recommended for both clinical practice⁵⁰ and research.⁵¹

Patients' actual functioning should be assessed at different ICF levels, encompassing impaired motor function, limited activity capacity, and limited activity performance.¹¹ Patient-reported outcome measures relating to activity and participation should be considered to complement data collected by technology or clinician observation.⁵⁰

Agreed assessments are important for predicting and monitoring recovery and outcomes at different levels of the ICF.⁸ Motor assessment results should be discussed with patients and their caregivers, together with assessments of other domains, such as cognition and communication, to establish a shared understanding of the patient's current status. Assessment results can also be used to gauge the patient's likely outcomes, and these expectations can be combined with the patient's personal goals to agree on the rehabilitation plan.⁵⁵

The treatment plan for post-acute stroke patients is influenced by clinicians' expectations of motor recovery and

Table 1. Recent consensus-based recommendations for motor assessments in stroke rehabilitation.

Source	Aim	Focus	Time post stroke	Recommended assessments
CAULIN ⁵⁰ 2021	Clinical practice	Upper limb	Within first week, 3-, 6- and 12-months; prior to discharge or transfer; before, during and after a rehabilitation program	FMA-UE, ARAT Extended: Kinematics, BBT, CAHAI, WMFT, NHPT, ABILHAND Supplementary: MI, CMSA, STREAM, FAT, MAS, sensor-based use of the upper limb
Core set ⁵² 2020	Clinical practice	Motor assessment	Day 2 ± 1 and 7, week 2 and 4, month 3, 6 and 12, and every following 6 months	FMA, ARAT, 10MWT, TUG, BBS, SIS
SRRR-2 ⁵³ 2019	Research	Upper limb quality of movement	Within first week, 3-, 6- and 12-months, 4 and 8 weeks recommended	Performance assays (2D reaching, finger individuation, grip/pinch strength) and 3D functional drinking task
SRRR-1 ⁵⁴ 2017	Research	Stroke recovery	Within first week, 3-months, 6- and 12-months recommended	NIHSS, FMA-UE and FMA-LE, ARAT, ability to walk, 10MWT, mRS and EQ-5D

CAULIN: Clinical Assessment of Upper Limb in Neurorehabilitation; FMA: Fugl-Meyer Assessment; ARAT: Action Research Arm Test; BBT: Box & Block Test; CAHAI: Chedoke Arm and Hand Activity Inventory; WMFT: Wolf Motor Function Test; NHPT: Nine-Hole Peg Test; MI: Motricity Index; CMSA: Chedoke-McMaster Stroke Assessment; STREAM: Stroke Rehabilitation Assessment of Movement; FAT: Frenchay Arm Test; MAS: Modified Ashworth Scale; 10MWT: 10-Meter Walk Test; TUG: Timed Up & Go; BBS: Berg Balance Scale; SIS: Stroke Impact Scale; SRRR: Stroke Recovery and Rehabilitation Roundtable; NIHSS: National Institutes of Health Stroke Scale; UE: upper Extremity; LE: Lower Extremity; mRS: Modified Rankin Scale; EQ-5D: European Quality of Life 5 Dimensions.

outcome.^{55,56} Patients with initially moderate to severe motor impairment are the most difficult to make accurate predictions for based on clinical assessments alone, yet accurate prognosis is most important for these patients.⁵⁷ Clinicians' prognoses are a source of variation that can produce inequitable access to rehabilitation services.^{55,57} Variation can be reduced when clinicians use objective prediction tools that combine standardized assessments to predict an individual patient's likely outcome. Prediction tools can be used to guide rehabilitation goal setting and tailor therapy, and doing so may improve rehabilitation efficiency.^{58,59}

Several tools have been developed to predict motor activity after stroke.⁵⁵ Validated tools that predict outcomes at specific time points for individual patients are summarized in Table 2. Most predict the probability of achieving a categorical activity capacity outcome for the upper limb or walking, defined using recommended clinical assessments. There are also tools available that can be used to predict recovery trajectories at any time in the first year post-stroke, for upper limb activity capacity⁶⁰ and independence in ADLs.⁶¹ Implementation,⁶² clinical impact,⁵⁹ and long-term accuracy⁶³ have been evaluated for one tool that predicts upper limb activity outcome.⁶⁴ Impact studies are needed to investigate the clinical benefits of prediction tools,⁶⁵ and evidence-based strategies are needed to support their successful and sustainable implementation.⁶²

Standardized assessments and prediction tools are expected to inform shared decision-making and goal-setting between clinicians, patients, and families. They can be used to guide the rehabilitation plan so that it maximizes the patient's chances of the best possible outcome. Standardized assessment of motor function at baseline is an essential element of all available prediction tools and needs

to be repeated during recovery to understand progress toward predicted outcomes. Standardized assessment schedules are therefore required for consistently effective rehabilitation planning and monitoring.

Motor rehabilitation interventions

The fourth section of the definition is supported by strongly recommended interventions from recent motor rehabilitation guidelines. National clinical practice guidelines for stroke rehabilitation were reviewed to summarize the current evidence-base on interventions targeting motor rehabilitation. We included guidelines written in English and Dutch since three of the core writing group members were Dutch-speaking. Guidelines needed to contain a section that specifically addressed "rehabilitation after stroke" to be considered. An overview of existing stroke guidelines was recently published summarizing "strong" recommendations for the broad field of stroke care.⁷⁰ The definition and framework here focus on motor rehabilitation and summarize motor-specific recommendations.

Five high-quality, evidence-based clinical practice guidelines published between 2016 and 2022⁷¹⁻⁷⁶ were reviewed to identify common strong recommendations. The Australian and New Zealand guidelines⁷⁵ were developed using the GRADE methodology (Grading of Recommendations, Assessment, Development and Evaluation)⁷⁷ and strong recommendations mean that the evidence supports a clear balance toward a desirable effect. The Canadian guidelines⁷³ defined strong recommendations as evidence from a meta-analysis of randomized controlled trials or consistent findings from two or more randomized controlled trials. The American guidelines⁷⁶ made strong recommendations based

Table 2. Cross-validated tools that predict outcomes at specific time points for individual patients.

Prediction tool	Domain	Predicted outcome	When prediction is made post-stroke	When outcome is measured post-stroke	Type of tool	Predictor variables
PUPPI ⁶⁶	Body function UL impairment	Binarized NIHSS arm score, <2 and 2–4	24 h	3 months	Scoring system	Age NIHSS
PREP2 ⁶⁴	Activity UL capacity	One of four categories of UL activity capacity: Excellent, Good, Limited, Poor	3–10 days	3 months	Decision tree	SAFE Age MEP status ^a NIHSS ^a
EPOS – Upper Limb ⁶⁷	Activity UL capacity	Probability of achieving at least 10 out of 57 points on the ARAT	2–10 days	3 months	Multi-variable equation	FMA-UE finger extension, MI shoulder abduction
EPOS – Walking ⁶⁷	Activity Walking capacity	Probability of independent walking, FAC score >3/5	3–10 days	3 months	Multi-variable equation	TCT sitting MI leg
TWIST ⁶⁸	Activity Walking capacity	Probability of independent gait, FAC score >3/5	7 days	4, 6, 9, 16 and 26 weeks	Scoring system	Age Knee extension strength BBS
Kwah ⁶⁹	Activity Walking capacity	Probability of independent gait, MAS item 5 score >2/6	Within 7 days	6 months	Multi-variable equation	Age NIHSS

PUPPI: Persistent Upper Extremity Impairment; UL: Upper Limb; PREP: Predict Recovery Potential; SAFE: Shoulder Abduction and Finger Extension; MEP: Motor Evoked Potential; NIHSS: National Institutes of Health Stroke Scale; EPOS: Early Prediction of Functional Outcome after Stroke; ARAT: Action Research Arm Test; FMA: Fugl-Meyer Assessment Upper Extremity; MI: Motricity Index; FAC: Functional Ambulation Categories; TCT: Trunk Control Test; TWIST: Tenecteplase in Wake-up Ischemic Stroke Trial; BBS: Berg Balance Scale; MAS: Motor Assessment Scale.

^aVariable required for a subset of patients.

on multiple randomized clinical trials or meta-analyses. The National Clinical Guidelines of the UK⁷² did not adopt a hierarchical grading system for the “strength” of recommendations. Instead, a formal consensus approach was used to identify the key recommendations in terms of their wider impact on stroke. Last, the guidelines from the Netherlands^{71,74} made strong recommendations based on RCTs with good methodological quality, sufficient size and consistency,⁷⁸ and systematic reviews with at least some RCTs that met the aforementioned criteria.

Interventions for motor rehabilitation with strong recommendations were extracted independently by two researchers (BE, MMN), compiled, and discussed in case of disagreement. Recommendations “in favor of” that were included in at least three of the screened guidelines are presented in Table 3, providing an overview of strongly recommended interventions for the motor rehabilitation domain with international consensus. The recommendations presented in Table 3 cover: (i) timing of rehabilitation delivery, (ii) general principles of motor control and motor learning, (iii) interventions for functions and activities involving the lower limb, postural control, and walking and (iv) upper limb functions and activities. Guidelines and recommendations are continuously updated based on available evidence, and therefore it is important for clinicians to consult recent and updated or living guidelines.

Discussion and conclusion

Motor rehabilitation is a key element of the stroke care pathway for people with persisting movement and mobility deficits. An expert panel agreed on the first definition of motor rehabilitation after stroke, which is supported by a contemporary motor rehabilitation framework for clinicians, educators and researchers. Figure 3 presents the definition and core elements of the motor rehabilitation process after stroke in an abbreviated pictorial format.

The strengths of this work include the expertise of the panel, the three-round process used for producing the definition, and the consultation with clinical stakeholders, integrating their feedback in final group discussions. Working group members were primarily European, in response to the assignment provided by the ESO, and also included colleagues from three global regions. The definition focuses on fundamental concepts which are likely similar across countries. The WHO rehabilitation definition is one sentence,⁴ however the panel constructed a definition paragraph which is more appropriate for multi-faceted concepts such as motor rehabilitation after stroke. It is rare for one definition to serve all stakeholders. Here we focused on the needs of educators, clinicians and researchers, rather than laypersons. Nevertheless, we obtained feedback from two people with lived experience, and a lay version with visual

Table 3. Overview of motor interventions with strong recommendations in at least three international clinical practice guidelines published between 2016 and 2022.

Strongly recommended	Guideline origin	Specific information
Time		
<i>Commencement of rehabilitation</i>		
Commence mobilization (out-of-bed-activity) within 48h of stroke onset unless otherwise contraindicated (e.g. receiving end-of-life care).	AU/NZ, CA, NL, UK, US	<p>AU/NZ:</p> <ul style="list-style-type: none"> • Patients with baseline NIHSS scores above 4 and below 7 have higher odds of favorable outcome when mobilized > 1x per day and spend less than 13.5 min per day in out-of-bed activities. • As patients tolerate more out-of-bed activity, better to increase frequency of sessions than duration of each session. • Particular care taken to avoid durations out of bed in people >76y and with more severe strokes (NIHSS > 7). • No rationale for restricting people to bed rest if they can move independently. <p>CA: excluded if medically unstable, severe cognitive impairment preventing from participating in therapy, inappropriate behavior putting self or others at risk, not willing to participate in program.</p> <p>NL: patients with severe stroke (NIHSS > 16) should be mobilized shortly (not longer than 10 min) and frequently (minimally 2 to 3 times a day) in the first days after their stroke. Other patients should be mobilized according to their ability.</p> <p>UK: patients with difficulty moving early after stroke who are medically stable should be offered frequent, short daily mobilizations (sitting out of bed, standing or walking) by appropriately trained staff, typically beginning between 24 and 48h of stroke onset.</p> <p>US: It is recommended that early rehabilitation for hospitalized stroke patients be provided in environments with organized, interprofessional stroke care.</p>
<i>Early supported discharge services</i>		
Offered to patients with mild to mod disability if appropriate home-based coordinated stroke services are available.	AU/NZ, CA, US	<p>AU/NZ: Where appropriate home-based coordinated stroke services are available, early supported discharge (ESD) services should be offered to stroke patients with mild to moderate disability.</p> <p>CA: ESD services, designed to reduce length of hospital stay and still provide same intensity of inpatient rehabilitation, are an acceptable form of rehabilitation and should be offered to a select group of patients when available and provided by a well-resourced, coordinated specialized team. Criteria for ESD candidacy include mild to moderate disability, ability to participate in rehabilitation from the point of discharge, and being medically stable.</p> <p>US: ESD services may be reasonable for people with mild to moderate disability.</p>
Principles		
<i>Intensity (amount of rehabilitation)</i>		
Rehab is structured to provide as much scheduled therapy (OT and PT) as possible.	AU/NZ, CA, NL	<p>AU/NZ: therapist should maximize the amount of active task practice during therapy sessions. Use of objective measurement of activity should be considered.</p> <p>CA: once deemed to be medically and neurologically stable, more therapy results in better outcomes.</p> <p>NL (in all phases): intensifying exercise therapy (more hours) compared to fewer hours leads to faster recovery of the dissociated movement, comfortable walking speed, maximum walking speed, walking distance, muscle tone, sitting and standing balance, the performance of basic activities of daily living, quality of life and degree of depression and feelings of anxiety.</p>
Mobility		
<i>General considerations</i>		
Patients should participate in training that is meaningful, engaging, progressively adaptive, intensive, task-specific and goal-oriented in an effort to improve transfer skills and mobility.	CA, UK, US	<p>CA: Therapy should include repetitive and intense use of patient-valued tasks that challenge the patient to acquire the necessary skills needed to perform functional tasks and activities.</p> <p>UK: People with loss of movement should be taught task-specific, repetitive, intensive exercises or activities that will increase strength.</p> <p>US: Intensive, repetitive, mobility-task training if gait limitations.</p>
Specific therapies		
<i>Weakness</i>		
Progressive resistance training to improve strength	AU/NZ	AU/NZ: For stroke survivors with reduced strength in their arms or legs, progressive resistance training should be provided to improve strength.
<i>Balance</i>		
Balance training	NL, UK, US	<p>NL (examined in ER, LR and RC): balance training during different activities improves sit- and standing balance and basic ADL activities.</p> <p>UK: People with significant impairment of their balance and walking ability after stroke should receive progressive balance training.</p> <p>US: Individuals with stroke who have poor balance, low balance confidence, and fear of falls or are at risk for falls should be provided with a balance training program.</p>

(Continued)

Table 3. (continued)

Strongly recommended	Guideline origin	Specific information
<i>Walking</i>		
Circuit class therapy (with a focus on overground walking practice)	AU/NZ, NL, US	<p>AU/NZ: Stroke survivors with difficulty walking should be given the opportunity to undertake tailored repetitive practice of walking (or components of walking) as much as possible, whereby circuit class therapy may be used (with a focus on overground walking practice).</p> <p>NL: circuit class training focused on walking and other mobility-related functions and activities improves the <i>walking distance/walking speed</i> (ER, LR, RC), <i>sit- and standing balance</i> (ER, LR, RC), <i>walking ability</i> (ER, LR, RC) and <i>reduced the inactivity</i> (LR, RC).</p> <p>US: Group therapy with circuit training is a reasonable approach to improve walking.</p>
Task and goal-oriented training that is repetitive and progressively adapted	AU/NZ, CA, NL, US	<p>AU/NZ: Stroke survivors with difficulty walking should be given the opportunity to undertake tailored repetitive practice of walking (or components of walking) as much as possible.</p> <p>CA: Task and goal-oriented training that is repetitive and progressively adapted should be used to improve performance of selected lower-extremity tasks such as sit to stand, walking distance and walking speed.</p> <p>NL: It is plausible that functional exercise therapy that can be performed in an environment as relevant to the patient as possible (task- and context-specific) has a positive effect on the skill to be learned skill itself. Elements of variation and sufficient repetition (repetition-without-repetition) appear to be important aspects for an effective learning process.</p> <p>US: Intensive, repetitive, mobility-task training is recommended for all individuals with gait limitations after stroke.</p>
Exercises which aim to improve aerobic fitness and/or muscle strength	NL, UK, US	<p>NL (examined in ER, LR and RC): training of the aerobic endurance in combination with strength training improves the <i>dissociated movements</i>, <i>muscle strength of the paretic leg</i>, <i>comfortable and maximal walking speed</i>, <i>walking distance</i>, <i>maximal oxygen absorption capacity</i>, <i>heart frequency during exercise</i>, <i>balance</i>, <i>amount of physical activity in daily life</i>, and <i>quality of life</i>.</p> <p>UK: People with stroke, including those who use wheelchairs or have poor mobility, should be advised to participate in exercise with the aim of improving aerobic fitness and/or muscle strength unless there are contraindications.</p> <p>US: Incorporating cardiovascular exercise and strengthening interventions is reasonable to consider for recovery of gait capacity and gait-related mobility tasks.</p>
Treadmill training with or without bodyweight support (BWS)	AU/NZ, CA, NL, UK, US	<p>AU/NZ: Stroke survivors with difficulty walking should be given the opportunity to undertake tailored repetitive practice of walking (or components of walking) as much as possible, for which treadmill training with or without body weight support may be used.</p> <p>CA: Treadmill-based gait training (with or without body weight support) should be used to enhance walking speed, and distance walked as an adjunct to over-ground training or when over-ground training is not available or appropriate.</p> <p>NL (examined in ER and RC): treadmill training with BWS improves <i>comfortable walking speed</i> and <i>walking distance</i>, but was not proven to be more effective than control condition for <i>sitting- and standing balance</i>.</p> <p>NL (examined in ER, LR and RC): treadmill training without BWS is more effective for improving <i>maximal walking speed</i> and <i>walking width</i> than conventional walking training.</p> <p>UK: People who are able to walk independently after stroke should be offered treadmill training with or without body weight support or other walking-orientated interventions at a higher intensity than usual care and as an adjunct to other treatments.</p> <p>US: Practice walking with a treadmill (with or without body-weight support) may be reasonable for recovery of walking function.</p>
Overground walking exercise training combined with conventional rehabilitation	AU/NZ, CA, NL, UK, US	<p>AU/NZ: Stroke survivors with difficulty walking should be given the opportunity to undertake tailored repetitive practice of walking (or components of walking) as much as possible through circuit class training focused on overground walking practice.</p> <p>CA: Over-ground training should be used to enhance walking speed, and distance walked, with treadmill-based gait training as an adjunct or when over-ground training is not available or appropriate.</p> <p>NL (examined in RC): more effective than treadmill training to improve <i>walking distance</i> and <i>reduce fear</i> for patients who can walk without physical support.</p> <p>UK: People with stroke who are able to walk with or without assistance should undergo task-specific walking training with a cardiorespiratory and/or muscle strength focus at sufficient intensity to improve endurance and walking speed.</p> <p>US: Practice walking with overground walking exercise training combined with conventional rehabilitation may be reasonable for recovery of walking function.</p>
Robot-assisted movement training in combination with conventional therapy	CA, NL, UK, US	<p>CA: Electromechanical (robotic) assisted gait training devices could be considered for patients who would not otherwise practice walking. They should not be used in place of conventional gait therapy.</p> <p>NL: improves, in patients who cannot walk independently, the <i>comfortable walking speed</i> (ER), <i>maximal walking speed</i> (ER and RC), <i>walking distance</i> (ER and RC), <i>heartrate</i> (ER), <i>sit- and standing balance</i> (ER), <i>walking ability</i> (ER) and <i>performing basic ADL activities</i> (ER and RC).</p> <p>UK: for people who cannot walk independently.</p> <p>US: for non-ambulatory or low ambulatory early after stroke.</p>

(Continued)

Table 3. (continued)

Strongly recommended	Guideline origin	Specific information
Ankle foot orthosis (AFO) to improve walking and balance, evaluated and individually fitted before long-term use	CA, NL, UK, US	CA, NL, UK, US: for people who have compromised ankle/foot stability and/or reduced ability to dorsiflex the foot ("foot-drop") that impedes safe and efficient walking should be offered an ankle-foot orthosis to improve walking and balance.
Functional electrical stimulation (FES)	CA, NL, UK, US	CA, NL, UK, US: in people with reduced ability to dorsiflex the foot ("foot-drop") should be offered FES to improve their gait as alternative to AFO, but effects may not be sustained.
Arm activity		
<i>Specific therapies</i>		
Traditional or modified constraint-induced movement therapy ((m) CIMT)	AU/NZ, CA, NL, UK, US	if 20° active wrist extension and 10° active finger extension in the affected hand AU/NZ: min. 2 h /a/ therapy/d for 2 w plus restraint for at least 6 h/d. Active, intensive task practice is key component, no evidence for use of restraint alone, CIMT only relevant for people with no or minimal cognitive deficits. CA: Traditional or modified constraint-induced movement therapy (CIMT) should be considered for a select group of patients who demonstrate at least 20 degrees of active wrist extension and 10 degrees of active finger extension, with minimal sensory deficits and normal cognition. NL: original CIMT (LR), low intensity mCIMT (ER, LR, RC) and high intensity mCIMT (ER, RC) improve <i>arm-hand skills</i> , <i>experience use of arm and hand</i> and <i>quality of movement</i> . Low-intensity CIMT further improves <i>basic ADL activities</i> , and original CIMT <i>quality of life</i> . US: CIMT or its modified version is reasonable to consider for eligible stroke survivors. UK: People with stroke who have 20 degrees of active wrist extension and 10 degrees of active finger extension in the affected hand should be considered for constraint-induced movement therapy.
Mental practice as an adjunct to conventional therapy	CA, UK, US	CA: Following assessment to determine if they are suitable candidates, patients should be encouraged to engage in mental imagery to enhance upper-limb, sensorimotor recovery. UK: People with stroke who have been assessed as cognitively suitable to participate in mental practice of an activity should be trained and encouraged to use it to improve arm function, as an adjunct to conventional therapy. US: Mental practice is reasonable to consider as an adjunct to upper extremity rehabilitation services.
Robot-assisted movement therapy as an adjunct to conventional therapy	NL, UK, US	NL: unilateral robot-assisted training of paretic shoulder and elbow improves <i>dissociated movements</i> and <i>arm strength</i> (ER, LR, RC) and reduces <i>atypical pain in the paretic arm</i> (ER, LR). Bilateral robot-assisted training of elbow and wrist improves <i>dissociated movements</i> and <i>arm strength</i> (ER, RC). UK: People with reduced arm function after a stroke should only be offered robot-assisted movement therapy as an adjunct to conventional therapy in the context of a clinical trial. US: Robotic therapy is reasonable to consider to deliver more intensive practice for individuals with moderate to severe upper limb paresis.
NMES as an adjunct to conventional therapy	CA, NL, UK, US	CA: FES targeted at the wrist and forearm muscles should be considered to reduce motor impairment and improve function. NL: NMES of paretic wrist- and finger-flexors and -extensors improves <i>dissociated movements</i> and <i>muscle strength</i> (ER), NMES paretic shoulder muscles improves <i>glenohumeral subluxation</i> (ER, LR, RC), EMG-NMES paretic wrist- and finger-extensors improves <i>dissociated movements</i> , <i>active ROM</i> and <i>arm-hand skills</i> (ER, RC). UK: People with reduced arm function after a stroke should only be offered neuromuscular electrical stimulation as an adjunct to conventional therapy in the context of a clinical trial. US: for individuals with minimal volitional movement within the first few months after stroke or individuals with shoulder luxation.
Activities of daily living (participation restrictions)		
Community-dwelling stroke survivors with confirmed difficulties in personal or extended ADL: should have specific therapy from a trained clinician (e.g. task-specific practice and training in the use of appropriate aids)	AU/NZ, NL, UK, US	AU/NZ: Community-dwelling stroke survivors with confirmed difficulties in personal or extended activities of daily living should have specific therapy from a trained clinician (e.g. task-specific practice and training in the use of appropriate aids) to address these issues. NL (examined in ER): positive effect on participation in leisure activity. NL (examined in ER and REC): not more effective for quality of life, mood and depression, motoric functions, ADL activities compared to other interventions. UK: People with limitations of personal activities of daily living after stroke should be referred to an occupational therapist with experience in neurological disability, be assessed within 72 h of referral, and be offered treatment for identified problems (e.g. feeding, toileting) by the occupational therapist, who should also involve other members of the specialist multidisciplinary team. US: All individuals with stroke should receive (I)ADL training tailored to individual needs and eventual discharge setting.

AUS & NZ: Australia and New Zealand; CA: Canada; UK: United Kingdom; US: United States of America; NL: Netherlands; NIHSS: National Institutes of Health Stroke Scale; OT: Occupational Therapy; PT: Physical Therapy; NMS: Neuromuscular Electrostimulation; TENS: Transcutaneous Electrical Nerve Stimulation; ADL: Activities of Daily Living; VR: Virtual Reality; BWS: Body Weight Support; AFO: Ankle Foot Orthosis; CIMT: Constraint-Induced Movement Therapy; mCIMT: modified constraint-induced movement therapy; FES: Functional Electrical Stimulation; EMG: Electromyography; rTMS: Repetitive Transcranial Magnetic Stimulation; HAR: Hyperacute Rehabilitation phase (0–24 h post-stroke); ER: Early Rehabilitation phase (24 h–3 months post-stroke); LR: Late Rehabilitation phase (3–6 months); RC: Rehabilitation in the Chronic phase (> 6 months).

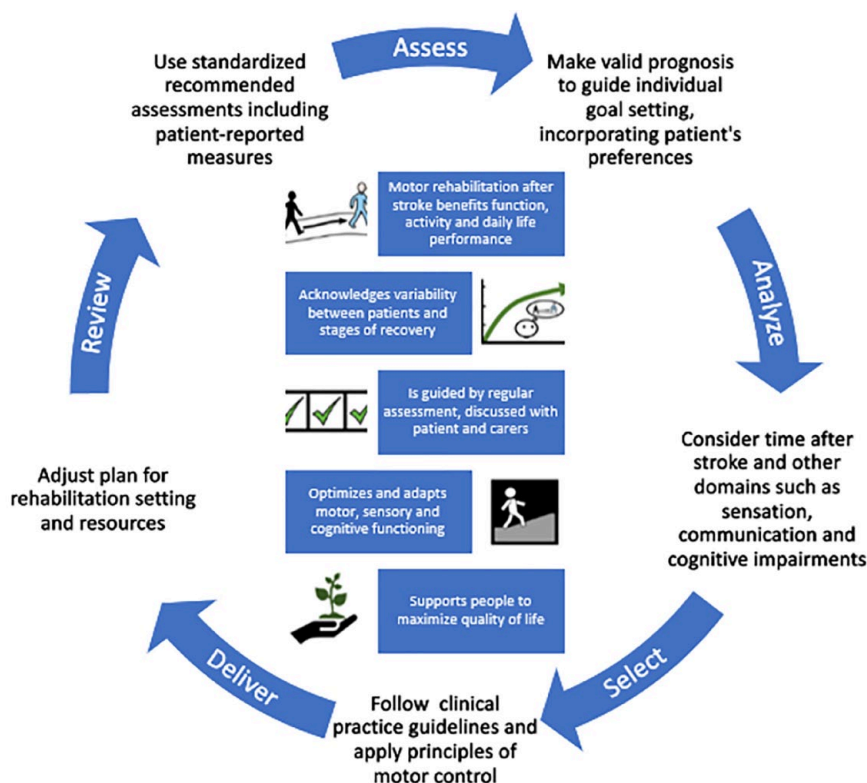


Figure 3. Pictorial abbreviated motor rehabilitation after stroke definition (center) and summarized process of motor rehabilitation after stroke.

supporting elements could help to communicate the concepts to patients and carers.

The formal definition of motor rehabilitation forms a base for future research and guideline development in the domain of motor rehabilitation. The working group is now developing motor rehabilitation guidelines based on the summary of interventions with strong recommendations presented here. Interdisciplinary rehabilitation teams need to follow evidence-based recommendations and integrate the views of patients and carers to improve life after stroke.

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