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Kinematic measures for upper limb robot-assisted therapy following stroke and correlations with clinical outcome measures: A review

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A B S T R A C T

Aim of the study: This review classifies the kinematic measures used to evaluate post-stroke motor impairment following upper limb robot-assisted rehabilitation and investigates their correlations with clinical outcome measures.
Methods: An online literature search was carried out in PubMed, MEDLINE, Scopus and IEEE-Xplore databases. Kinematic parameters mentioned in the studies included were categorized into the International Classification of Functioning, Disability and Health (ICF) domains. The correlations between these parameters and the clinical scales were summarized.
Results: Forty-nine kinematic parameters were identified from 67 articles involving 1750 patients. The most frequently used parameters were: movement speed, movement accuracy, peak speed, number of speed peaks, and movement distance and duration. According to the ICF domains, 44 kinematic parameters were categorized into Body Functions and Structure, 5 into Activities and no parameters were categorized into Participation and Personal and Environmental Factors. Thirteen articles investigated the correlations between kinematic parameters and clinical outcome measures. Some kinematic measures showed a significant correlation coefficient with clinical scores, but most were weak or moderate.
Conclusions: The proposed classification of kinematic measures into ICF domains and their correlations with clinical scales could contribute to identifying the most relevant ones for an integrated assessment of upper limb robot-assisted rehabilitation treatments following stroke. Increasing the assessment frequency by means of kinematic parameters could optimize clinical assessment procedures and enhance the effectiveness of rehabilitation treatments.

Contents

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1. Introduction

Strokes are currently the second largest cause of disability-adjusted life years (DALYs) after ischemic heart disease in developing countries, and is the third largest cause of DALYs in developed countries (after ischemic heart disease and low back and neck pain) [1]. The functional activities of stroke survivors are significantly affected due to motor impairments, particularly in terms of upper limb disability. The impairment reduction and the recovery of upper limb are key objectives in stroke rehabilitation, which contribute to enhancing the quality of life of stroke survivors.

The time available for stroke rehabilitation is limited. The Copenhagen Stroke Study reported data showing that recovery in activities of daily living (ADLs) function occurs in most patients within 13 weeks from stroke onset. After this time, the rehabilitation did not affect ADLs function to any significant degree [2]. It has been suggested that the first month after stroke represents a critical time period for treatment initiation and motor recovery should not be expected more than five months after onset [3–5]. Therefore, starting the most appropriate rehabilitation treatment as early as possible and adapting it to the motor recovery of the patient may contribute to improving the outcome of the rehabilitation treatment [6–8].

Rehabilitation is labor-intensive for therapists, and therefore may be limited in duration or intensity by the fatigue of the therapist in lifting the patients' limbs, or by shortages in personnel. In recent years, robots have been increasingly used to assist upper limb training and rehabilitation. Using a robotic system, the therapist can provide their patients with repetitive movement training, or massed practice [9], and thus reduce the physical demands of their work [10].

Another important aspect of robotic rehabilitation is the capacity of devices to more precisely target specific movement impairments. Several studies have investigated the strategies aimed at the improved targeting of specific movement impairments using robotics [11,12]. In addition, sensors on the robotic device may provide the therapist with real-time, objective measures of patient motor capabilities, which can help to follow patient progress, to evaluate the effectiveness of different interventions, or to adapt to specific patients' motor recovery trend [13,14].

There are still some major limitations of using robotic systems for upper limb rehabilitation, such as the limited range of movements possible and the lack of carry-over gains to functional movements of the upper limb [15]. Robotic systems nevertheless provide safe, effective and economical treatment to patients with motor impairments [16]. The implementation of more appropriate and novel interventions using robotic systems is important to enhance recovery.

The cost of treatment is a significant problem. In the USA, the mean costs of hospitalization are approximately $20,000, depending on the age and sex by diagnosis status and stroke type [17]. In addition, rehabilitation costs represent a high economic burden that stroke patients have to face. Although Lo et al. [18] showed that matched intensity robot-assisted therapy did not significantly improve motor function compared with conventional therapy in patients with long-term upper limb deficits after stroke, the average per-patient cost of therapy for patients receiving robot-assisted therapy was lower than for patients receiving intensive comparison therapy ($5152 and $7382, respectively). After 36 weeks, the average total cost (therapy plus the cost of all the other health care services) was $17,831 for robot-assisted therapy, $19,746 for intensive comparison therapy and $19,098 for usual care [18]. Thus, an important goal is to develop technologies that enable stroke patients to receive intensive therapy at a lower cost.

The evaluation of the motor recovery of stroke patients following upper limb robot-assisted rehabilitation is based mainly on clinical scales [19]. The clinical assessment is usually performed twice - before and after the training. Evaluating motor recovery during training using clinical outcome measures is difficult because of the limited time and resources. In recent studies, kinematic parameters recorded by the robot have also been proposed as indicators of motor performance. In contrast to clinical outcome measures, kinematic measures can be easily analysed after each training session. In addition, instrumentation on board the robot can record kinematic and force data which could provide the new assessment measures with improved objectivity, repeatability, precision and ease of application [10]. A large number of kinematic measures have been proposed, some of which have been given different names despite having the same meaning. Although the suitability of kinematics to capture the changes intended in subjects has been summarized [20], there is no consensus on the most appropriate outcome measures nor on the kinematic parameters that should be used.

Kinematic measures have become more important in the evaluation process, because motor performance can be highlighted through the analysis of the kinematic parameters recorded. For instance, the number of peaks in the speed profile had been used to assess movement smoothness [21–23]. The correlations between kinematic parameters and clinical scales have been proposed [10,22,24–32]. Some models for estimating the Fugl–Meyer Assessment (FMA), Motor Status Score (MSS), Modified Ashworth Scale (MAS), and Motor Power (MP from kinematic and kinetic metrics have been proposed [33]. The agreement between robotic measures with clinical scales was tested in 11 individuals with chronic stroke [32]. The aim of these correlation values is to provide a more quantitative and reliable assessment method during the training process, i.e., the kinematic parameters can be used as a fast and reliable evaluation metric that could detect changes in patient performance after each training session. In addition, these correlation values can provide visual evidence for selecting an appropriate set of kinematic measures and clinical scales to evaluate motor impairment recovery after therapy.

In this study, a systematic review was performed of the kinematic measures for upper limb robot-assisted therapy and their correlation with clinical scales. The aims of this work are: (i) to identify kinematic parameters recorded by robot devices for evaluating motor recovery after intervention; (ii) to classify these kinematic parameters into the International Classification of Functioning, Disability and Health (ICF) domains; (iii) to analyse the correlations between these parameters and clinical scales. The results of this review could be used to identify appropriate clinical outcome measures and kinematic parameters to be used as an integrated assessment method.

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