Human Simulation in Stroke Patients Rehabilitation

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Abstract

Introduction: Different types of neurological deficits and sequels in the upper extremities that affect the activities of daily living in patients who have undergone stroke, have been analyzed from a subjective clinical point of view. Prognosis recovery after stroke depends on many factors, among which are included individualized program of rehabilitation and cooperation of patients.
Objectives: Simulation patients in the beginning of stroke. The aim of this work is to show a novel environment to simulate the initial improvement upper limb functions a few days after stroke and simulate the functional recovery of patients under a rehabilitation program.
Methods: Twenty-nine patients in the first four days post stroke were selected. Inclusion criteria were: over eighteen years of age, collaborative patients, and neurological deficits in upper extremities post stroke without a previous history of stroke of motor sequelae second to other neurological or osteoarticular diseases that might identify pre-existing disability. Assessments were performed with 3-4 days and 7 days and 1, and 3 months post stroke recording the following variables: demographics, stroke type, stroke classification according to the Oxford scale, neurological deficit determined by the NIHSS, disability measures (Barthel's Index, Rankin Scale), assessment of the motor dysfunction of the upper extremities according to the Fugl-Meyer Scale as well as muscle tone (Ashworth's Scale) and muscle balance of the upper extremities. We measured the deficits of angles, lengths and range of motion for the arm and hand affected. These measures were implemented in a virtual environment with 29 DOF for each arm and hand.
Discussion of Results: The different types of deficit and sequelae seen in the upper extremities of stroke patients impairing their activities of daily living have been analysed from a subjective clinical standpoint based on clinical and functional assessments. The prognosis for recovery of each patient very much depends on many factors, which can be found in the rehabilitation program and individual goals together with the collaboration afforded by the patients themselves while they are unaware a priori of the objective outcome of the rehabilitation process.

Keywords: Stroke, upper extremity, simulation, recovery.

1. Introduction

According to the World Health Organization (WHO) definition, stroke is a clinical syndrome that is characterized by rapidly developing global or focal loss of brain function lasting over 24 hours or leading to death with no apparent aetiology other than vascular (WHO 2007). Two large families of brain vascular diseases have been defined on the basis of ischemic or haemorrhagic lesions.
Stroke amounts to the second cause of death and the first cause of disability in Western countries and its importance grows at the same pace as population becomes older. It is deemed that 50% of stroke survivors will have some kind of residual deficit that will require assistance for activities of daily living (ADL) (Wolfe CD, 2000).
Reaching early functional prognosis in stroke patients allows physicians to communicate this to patients and their families and is also useful in correctly setting the kind of rehabilitation program and goals while stratifying patient groups with comparable prognosis that simplifies investigations.
Most published studies on the evolution and functional prognosis of stroke patients dwell around global recovery mainly encompassing gait and ADL.

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The objective of present study is to simulate patients in the beginning of stroke. The aim of this work is to show a novel environment to simulate the initial improvement upper limb functions a few days after stroke and simulate the functional recovery of patients under a rehabilitation program.

2. Materials and Methods

This is a longitudinal prospective study including patients admitted in a Neurology Department in an acute care hospital with altered mobility of the upper extremities (UE) second to acute stroke.
These are the inclusion criteria:

- Patients, 18 years of age or older, with UE paresis second to acute stroke of under 4 days of duration;
- Patients without a previous history of stroke or motor sequelae second to other neurological or osteoarticular diseases that could disclose pre-existing disability.

These were the exclusion criteria:

- Patients who could not be easily reached after discharge to ensure proper follow-up;
- Lack of informed consent by the patient or caregiver to be included in the present study.

Assessment was performed on 3-4, and 7 days and 1, and 3 months post-stroke.
Initial assessment (3-4 days) included recording of known functional prognosis variables and demographic variables including gender, age, stroke type (ischemic or haemorrhagic) the Oxford classification (Bamford J et al., 1991) and the National Institutes of Health Stroke Scale (NIHSS) (Goldstein LB et al., 1989) scores. All assessments included variables measuring motor function. As regards disability the Barthel's Index Scale (BI) (Mahoney FI and Barthel DW, 1965) and the result oriented scale Rankin (Wolfe CD et al., 1991) were used and to assess motor control of the UE the Fugl-Meyer Scale (FM) (Fugl-Meyer AR et al., 1975). Muscle tone was assessed with the Ashworth's Scale (Ashworth B et al., 1987) and muscle balance for each articulation of the UE with the strength grading system of the Medical Research Council (Medical Research Council, 1976).

3. Results

The present study included 29 patients, one of whom passed away one month post stroke. Median age was 71.6 years with standard deviation of 12.143 with 10 women and 19 men. Stroke aetiology of 86.2% of patients was ischemic and haemorrhagic for the remainder, where the atherothrombotic aetiology was the most frequent at 79.3%. According to the Oxford classification the most frequent stroke type was lacunar infarction (LACI) totalling 51.72% followed by partial anterior circulation infarction (PACI) to 24.13%, total anterior circulation infarction (TACI) to 13.80% and posterior circulation infarction (POCI) to 10.35%.
Scores from the NIHSS, Rankin, BI, Ashworth's and FM for each assessment time point are shown in figures 1 through 5.
Patients with a decreased muscle tone fared worse in improving motor control of the different articulations of the UE as shown in the recorded scores in figures 4 and 5.

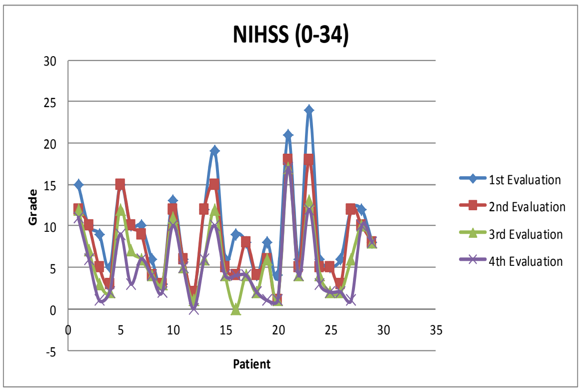

Figure 1. NIHSS scores at each assessment time point per each patient included.

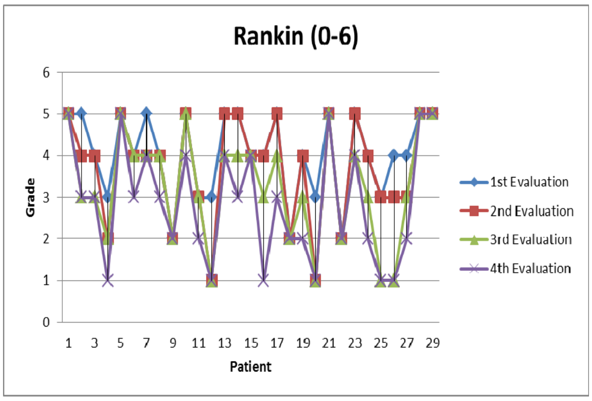

Figure 2. Rankin scores at each assessment time point per each patient included.

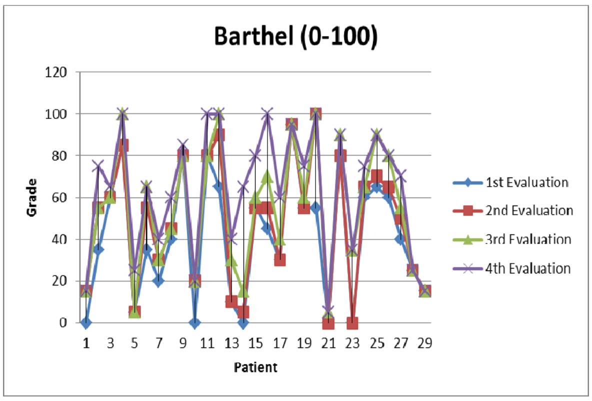

Figure 3. Barthel's Index scores at each assessment time point per each patient included.

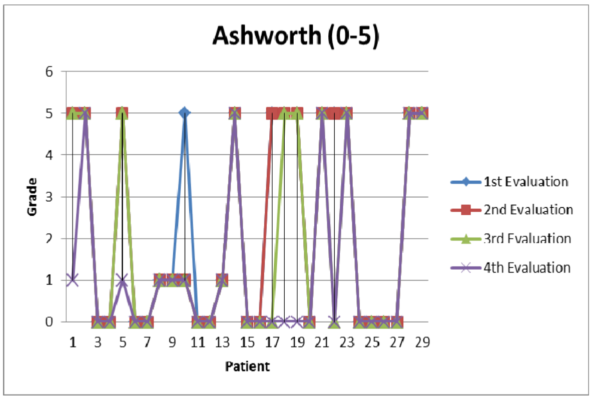

Figure 4. Ashworth's Scale scores at each assessment time point per each patient included.

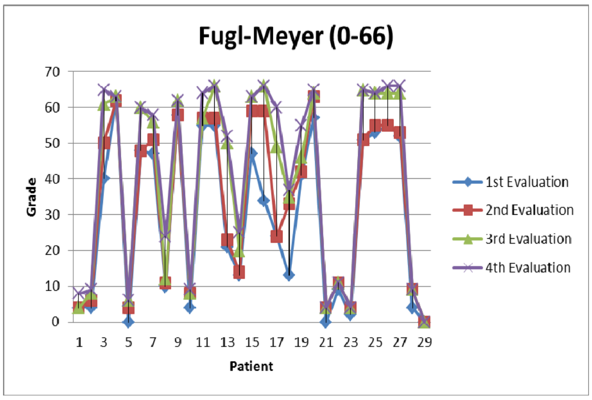

Figure 5. Fugl-Meyer Scale scores at each assessment time point per each patient included.

The following figures illustrate a list of patients and the FM Scale which assesses motor control of the UE. Scores under 0 point to very low or absent control while scores above 66 point to normal control of the UE (Figs. 6 and 7).
Figure 8 shows a patient that had no improvement at any of the assessment time points.

Figure 6. Patient at a 3 month control whose recovery was good scoring 55 on the FM Scale whilst at the first assessment performed the score was 9. Grip lacks fine dexterity.

Figure 7. Same patient showing more dexterity in his grip when less precision is required.

Figure 8. Patient showing no improvement, complete lack voluntary motor control. Initial and final FM Scale score was 4.

3.1. Simulation

We approached simulation for each status of each patient by using the model shown in Figure 9. The model has 25 degrees of freedom (DOF) aimed to apply both direct and inverse kinetics.

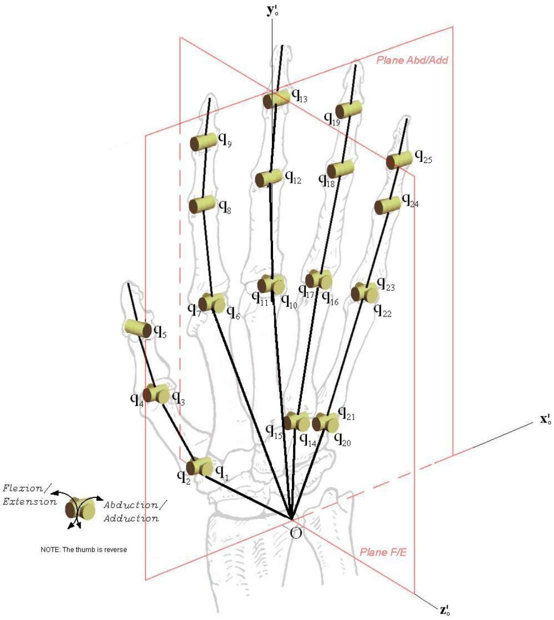

Figure 9. The 25-DOF. Posterior view of right hand.

For the whole of the UE we used a model with 29 DOF. Figure 10 shows the 3-D depiction of the model.

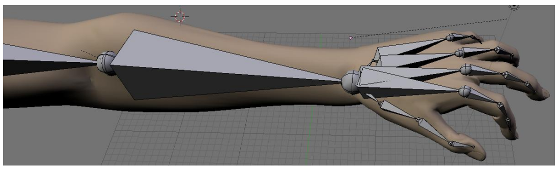

Figura 10. Schematic model of the left arm and hand with 29 DOF.

The mathematic formulation to be applied to the model was previously published in Peña-Pitarch et al., 2005 and reads as follows. Position vector is defined by $\mathbf{p}(\mathbf{q}^i)$ which with respect to the coordinate system is:

$$\begin{bmatrix} \mathbf{p}(\mathbf{q}^i) \\ 1 \end{bmatrix} = {}^0A_1 {}^1A_2 \ldots {}^{n-1}A_n \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Where $\mathbf{q}^i = [\mathbf{q}_1 \ldots \mathbf{q}_n]^T$ $i = I, II..$ where I reflect the thumb, II the index, and so on. Two i reflect the wrist and two for the elbow, where n reflects the maximum number of DOF considered, in this case totalling 29.

For a global coordinate system located on the elbow the vector position is as follows:

$$\begin{bmatrix} \mathbf{w}(\mathbf{q}^i) \\ 1 \end{bmatrix} = [{}^0\mathbf{H}_i] \begin{bmatrix} \mathbf{p}(\mathbf{q}^i) \\ 1 \end{bmatrix}$$

With the application of the homogeneous transformation matrix, we can write:

$${}^0T_i = {}^0A_1 {}^1A_2 \ldots {}^{n-1}A_n = \begin{bmatrix} n_x & o_x & p_x & d_x \\ n_y & o_y & p_y & d_y \\ n_z & o_z & p_z & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where the vector $\mathbf{d} = [\mathbf{d}_x\ \mathbf{d}_y\ \mathbf{d}_z]^T$ is the position of the fingertip and each matrix T has the angles for each joint and finger.

The following figures show the simulation obtained by using the proposed model together with the data obtained from assessment scales and measured angles for each joint and each patient.

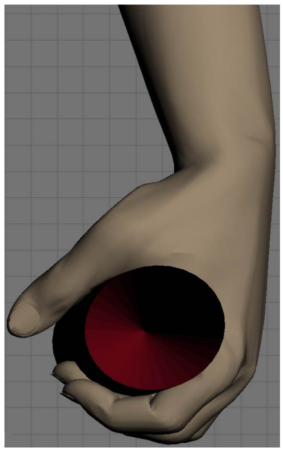

Figure 11. Hand simulation shown in Figure 6.

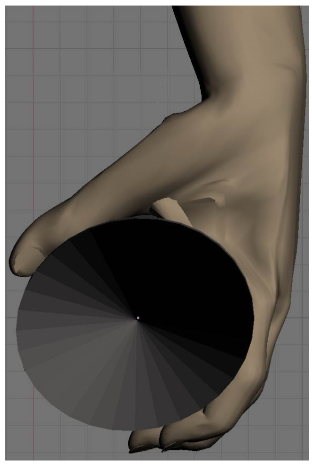

Figure 12. Hand simulation shown in Figure 7.

4. Discussion

The different types of deficit and sequelae seen in the UE of stroke patients impairing their ADL have been analyzed from a subjective clinical standpoint based on clinical and functional assessments. The prognosis for recovery of each patient very much depends on many factors, which can be found in the rehabilitation program and individual goals together with the collaboration afforded by the patients themselves while they are unaware a priori of the objective outcome of the rehabilitation process.
Various studies have proved that the functional recovery prognosis of the UE basically depends on the apparition of motor control and muscle balance at the elbow level and more importantly the hand as assessed within the first few days post stroke (Kwakkel G et al., 2007; Mirbagheri MM et Rymer WZ 2008; Nijland RH et al., 2010). Neuroimaging has also been used, mainly new modalities of MRI (Pineiro R et al., 2000; Binkofski F et al., 2001) as well as motor evoked potentials, as tools to predict a functional prognosis of the UE (Hendricks HT el al., 2003; Nascimbeni A et al., 2006) although they are rarely used in the daily clinical practice. Kinetic and kinematic studies have slowly gained a role during examination affording support to and complementing clinical assessments (Castiello U, 2005; Lang CE et al., 2006).

Many authors have for long studied and applied simulation of the human body based on current anatomy knowledge giving way to several virtual human models (Badler et al., 1993; Abdel-Malek K et al., 2006) with application mainly in the automotive industry. Only rarely have such models been applied in the simulation of individuals with sequelae from neurological dysfunction. Although it is mentioned above that these simulations are of use in determining functional prognosis during the first few days post stroke and are a useful tool for physicians and physical therapists to determine rehabilitation goals and programs, simulation is also a powerful tool in designing tools and gadgets that stroke patients could benefit from with the aim to improve quality of life and independence to the maximum degree possible.

Figures 11 and 12 show the simulation of the grip of a patient who received a low rating in the first days of admission (FM 9), its evolution has been favorable (FM 55) and as seen in the figures yet reached the grip of people not affected by neurological sequelae. This suggests that existing models in literature for simulation in this type of person are invalid.
This work aims to create specific simulation tools for these people.

5. Conclusion

Simulation in patients with neurological sequelae second to stroke is no trivial issue, as every patient will show a different affectation profile and recovery patterns led by dysfunction in connection with neurological lesions and predictive clinical factors assessed from a subjective standpoint using clinical assessment scales.
Simulation applied to patients with neurological deficit has widened its scope that can be applied to different neurological diseases. Research on grip simulation of healthy individuals is at a very advanced stage, although much work remains to be done.
Although the results obtained to date are quite satisfactory and highly applicable, there is much to be done, such as the addition of muscle system into the model and establishing a clear link between the simulation model and the clinical assessment scales. In the humble view of the authors of this work, there is a promising path in attaining fully objective assessment scales.

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