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Body representation after a stroke in the brainstem

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Résumé

Lorsqu'une lésion a lieu dans le tronc cérébral (TC), cela peut causer une instabilité posturale et des problèmes d'équilibre, ce qui pourrait être dû à une perception inadéquate de l'orientation du corps dans l'espace. L'objectif de cette étude était de déterminer les effets d'un accident vasculaire cérébral (AVC) dans le TC sur la représentation du corps dans le plan horizontal, ainsi que de déterminer les liens avec des troubles posturaux et la neuroanatomie. Quarante patients avec un AVC au niveau du tronc cérébral gauche (TC-G) ou droit (TC-D) furent comparés à 20 sujets contrôles appariés. Le « droit devant subjectif » (DDS) fût investigué en utilisant un dispositif permettant de mesurer les inclinaisons et les déviations latérales. Les patients TC-G avaient un décalage du DDS controlatéral à la lésion, alors que chez les patients TC-D, la représentation de la ligne médiane du corps était précise et ne différait pas de celle chez les sujets contrôles. Ces résultats mettent en évidence une asymétrie de la représentation du corps associée avec des lésions du TC-G s'étendant dans l'hémisphère cérébral droit. Cette déviation n'apparaît qu'après une lésion gauche, ce qui suggère une dominance vestibulaire. Ces résultats offrent une nouvelle perspective dans la neuro-réhabilitation de troubles posturaux après un AVC, avec comme focus une correction de la représentation du corps dans l'espace.

Mots-clés : Représentation du corps ; neuroanatomie ; AVC du tronc cérébral ; noyau vestibulaire

Abstract

Lesion occurring in the brainstem may cause a postural tilt and balance disorders, which could be due to an inaccurate perception of the body orientation. The objective of this study was to determine the effects of a brainstem stroke on body representation in horizontal plane, and links with impaired posture and neuroanatomy. Forty patients with stroke in left brainstem (L-BS) or right (R-BS) were compared with 20 matched control subjects (C). The subjective straight-ahead (SSA) was investigated using a method disentangling lateral deviation and tilt components of error. The L-BS patients had contralesional lateral deviation of SSA. By contrast, in R-BS patients, the representation of the body midline was fairly accurate and did not differ from that of control subjects. This work highlights an asymmetry of representation of body associated with left brainstem lesions extending to the right cerebral hemisphere. This deviation appears only after a left lesion, which may point to a vestibular dominance. These results open a new perspective of neuro-rehabilitation of postural disorders after a stroke, with the correction of the representation of body orientation.

Keywords: Body representation; neuroanatomy; brainstem stroke; vestibular nucleus

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Liste des abréviations

C : Control subjects

GMV : Gluteus medius muscle vibration

L-BS : Patients with stroke in left brainstem

MNI : Montreal Neurological Institute

MRI : Magnetic Resonance Imaging

NMV : Neck muscles vibration

PASS : Postural Assessment Stroke Scale

R-BS : Patients with stroke in right brainstem

ROI : Region Of Interest

SSA : Subjective straight-ahead

VLSM : Voxel-based Lesion-Symptom Mapping

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Présentation

L’article de recherche rédigé en anglais dans le cadre de la présente étude sera présenté dans la prochaine section. Il a déjà été soumis à la revue *European Journal of Neurology*.

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INTRODUCTION

Annually, 15 million people worldwide suffer a stroke. Of these, 5 million die and another 5 million are left permanently disabled, placing a burden on family and community[1]. The stroke frequency is age-related, and the progressive aging of the population suggests an increase in the number of people suffering from brain damage in the coming years[2]. One of the causes of disability in patients suffering a stroke are postural disturbances[3], which increase the risk of falls and are a source of significant loss of autonomy for the patient. Strokes can also lead to vestibular symptoms, such as dizziness and vertigo. These symptoms seem to be more frequent when the stroke occurs in the right hemisphere or in the brainstem[4,5]. Brainstem strokes are less frequent, but still represent 10% of all brain strokes[6]. As for possible cognitive impairments following a stroke, the literature doesn't point out a "typical profile" as it can vary a lot depending on the areas affected and the extent of the lesion.

To date, the mechanisms of the postural disturbances following a stroke are not fully understood. Many authors agree on a right hemispheric localization for spatial cognition and especially for the mental development of body representation in space[7–10]. This hypothesis could explain why patients experiencing a right brain injury have a poorer quality of life in terms of balance than those whose injury is located in the left cerebral hemisphere[11–13].

The representation of the body in space requires the integration of stimuli from three sensory systems: the proprioceptive fibers, visual fibers and vestibular fibers. These inputs seem to be mainly integrated in the parietal cortex, more precisely in the parieto-insular vestibular cortex[14,15]. This information is processed in different spatial reference systems, including the allocentric and egocentric reference frames, that allow the person to imagine his body in space, and to maintain its position and moves[8,16]. Body representation disorders can be studied by different measures, in particular with the subjective straight-ahead (SSA) [12].

SSA protocol consists in imagining a line starting from the mid-sagittal plane of the body at the navel and projecting ahead. It was first developed by pointing with the finger straight in front of the midline[17] and, more recently, by adjusting a movable bar in peri-personal space in front of the centre of the trunk[18].

Studies using this method in healthy subjects demonstrated a slight systematic shift of the SSA to the left[10,19]. The SSA also seems to be influenced by the body positioning (sitting or supine position)[20] and by the trunk orientation[21] in the sagittal plane. It has also been shown that results can be modulated by applying stimulation to the vestibular, proprioceptive and/or visual systems[22–24], or by guiding visual attention in peri-personal space[25].

Patients with right hemispheric lesion show an ipsilesional deviation of the SSA amplified in case of spatial neglect[18,26] or associated hemianopia[27,28]. More recently, studies in patients with peripheral vestibular lesions[29] or vestibulopathy[30] have shown that patient with left vestibular lesion had similar deviation of SSA. This predominant rightward deviation demonstrates that the translation is most important when the lesion is left-sided, supporting the theories of asymmetry of the vestibular system with a dominance of the left vestibular fibers in the direction of the right cerebral hemisphere.

The perception of body representation is implicated in different regions, like the parietal cortex, the visual cortex, the intraparietal sulcus, the parieto-insular vestibular cortex, the temporal gyrus and the dorsolateral premotor cortex[9,10,14,31]. In terms of the egocentric reference frame, cortical activity is mostly present in the occipital cortex and the right superior parietal cortex, as well as the left insula[9]. Bias in the body representation in space, leading to postural difficulties, are related to lesions in the anterior parietal cortex and the superior temporal gyrus. More precisely, imbalances are associated with lesions of the posterior insula and the temporoparietal cortex[31].

The objective of this study was to evaluate the impact that a stroke in the brainstem has on the body representation and the posture. The aim was also to study the neuroanatomical networks in connection with these imbalances, to better understand the implication of the vestibular networks and improve the care of patients who then develop postural disorders.

METHODS

Participants

The participants, right-handed, were selected in the neurology department of the University Hospitals of Geneva following their first admission to a stroke of the left or right brainstem, whether it was ischemic or haemorrhagic (Figure 1). All lesions were confirmed by MRI. Any neurological or psychiatric history meant an exclusion in order to avoid creating bias in carrying out the assigned task.

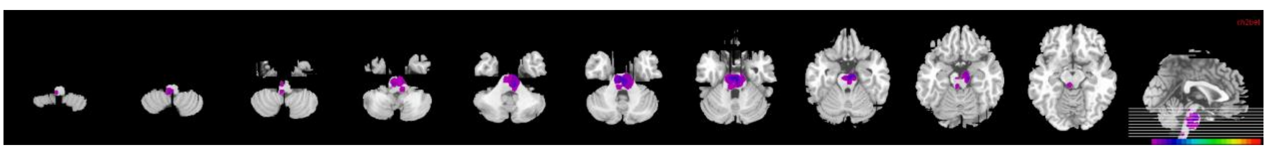

Figure 1. Overlap of the brain lesions in the 40 patients.

Two groups (Table 1) were obtained, consisting of 20 patients with a lesion of the left brainstem (L-BS) and 20 patients with damage to the right brainstem (R-BS). There was no significant difference ($p = 0.17$) in terms of size of lesion between the two groups. The patient groups were compared to a control group (C) consisting of 20 healthy volunteers (9 women and 11 men, mean age 65.8 +/- 10.9 years, right-handed). Differences in age and education levels were not clinically significant between the three groups ($p > 0.05$). Informed consent was obtained from the patients and the control participants in accordance with the declaration of Helsinki. The study was approved by the local ethics committee.

Table 1 Demographic and clinical data

	L-BS	R-BS	*p*
Age	67.6 (4.6)	68.10 (5.3)	0.38
Gender (F/M)	9/11	11/9	-
Etiology (infarct/hemorrhage)	18/2	17/3	-
Time since stroke (days)	287.3 (224.9)	341.88 (231.95)	0.31
Lesion volume (mm^3)	1006.3 (435.3)	1297.2 (812.9)	0.17
PASS score (/36)	27.1 (7.6)	32.7 (5.2)	0.03 *

Abbreviations: F, female; L-BS, left brainstem stroke patients; M, male; PASS, Postural Assessment Scale for Stroke Patients; R-BS, right brainstem stroke patients.

Postural assessment

Postural stability was estimated using the postural scale PASS (Postural Assessment Scale for Stroke Patients)[32], which assesses posture after a stroke based on several criteria: holding a sitting or standing position, with or without support, changing from one posture to another, standing on the non-paretic limb and then the paretic limb, standing up, sitting down and picking up an object on the floor without losing balance. The PASS was administered at the same time as the SSA.

Body representation assessment

Orientation in the horizontal plane

Apparatus: Participants were seated on a chair with a vertical backrest. Their head was held up in the trunk direction. They were facing a horizontal metal rod (25 cm), centered 50 cm in front of them, which could be simultaneously rotated and translated along a 100 cm wide slit in a horizontal plate located at navel level (Figure 2). A disc mounted between the rod and the plate avoided haptic cues. Two potentiometers gave the rotation angle (accuracy = 0.1°; positive value = clockwise orientation) and the translation position (accuracy = 0.1 cm; positive value = rightward displacement). All tests were performed in a dark room so that all vertical and horizontal visual cues were excluded. Ten red light emitting diodes were inserted in the upper side of the rod to make it visible in darkness. The whole apparatus was centered relative to the body midline.

Procedure: The participants were instructed to imagine a line starting at their navel and extending away straight ahead of their trunk, and to adjust the position of the rod in such a way that its two extremities stood on this virtual line. The rod was handled at its centre with the right hand. Before each trial, the rod was initially translated to –15 cm, 0 cm or +15 cm and rotated to –45°, 0° or +45°. Two trials were run for each of the nine initial positions (3 translations X 3 rotations). So, there was 18 trials in total and the order of the trials varied randomly across subjects.

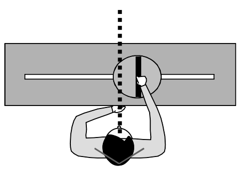

Figure 2. Apparatus used to assess the SSA in the horizontal plane.

Statistical analyses

Behavioral analysis

To characterize the representation of body orientation in the horizontal plane, each dependent variable was analyzed using ANOVAs (Statistica software). The translation (in mm) and rotation (in degrees) data were analyzed separately. For each participant, measures obtained for the trials performed in the same initial conditions were averaged before analysis. The ANOVAs included the between-factor group (L-BS, Patients with stroke in left brainstem; R-BS, Patients with stroke in right brainstem; C, control subjects). Post Hoc comparisons were achieved using the Scheffé test.

Lesions analysis

MRIs, carried out in the acute phase after the stroke, allowed us to precisely establish the topography of the subjects' lesions. They were then manually rebuilt on axial planes using the MRIcro software[33]. The contours of each lesion defined a ROI (Region Of Interest) in 3D, which was normalized to a standard and then superimposed on MRI planes. VLSM software (Voxel-based Lesion-Symptom Mapping[34]) was used to correlate the behavioral outcomes and the lesions observed. The subjects were divided into two groups according to the presence or absence of a lesion in each 3D region or "voxel", and then a T-test was used with the clinical deviations to obtain a spatial overlap of the lesions. A colour gradient representing the distribution of the brain lesions based on the T-test values was made; the yellow areas corresponding to the most affected regions and the red areas being the ones less affected.

RESULTS

Perceived body orientation

Orientation in the horizontal plane

The SSA showed significant differences in translation between groups ($F (2, 57) = 12.8$, $p < 0.001$). The center of the rod was closer to the mid-sagittal line in C subjects (0.38 +/- 1.44mm) and R-BS subjects (2.91 +/- 10.04 mm) with no significant difference ($p = 0.739$; Cohen's $d = 0.247$). The L-BS group, on the other hand, showed a right deviation (15.70 +/- 14.54 mm) significant compared to both group C ($p < 0.001$; Cohen's $d = 1.493$) and group R-BS ($p = 0.001$; Cohen's $d = -1.246$) (Figure 3).

Regarding the rotation of the SSA, there was no significant difference observed between the three groups ($F (2, 57) = 3.07$, $p = 0.054$), the directions indicated by the C subjects (-0.42° +/- 0.59°), R-BS (0.66° +/- 1.34 °) and L-BS (0.16° +/- 1.86°) always being close to the mid-sagittal plane (Figure 3).

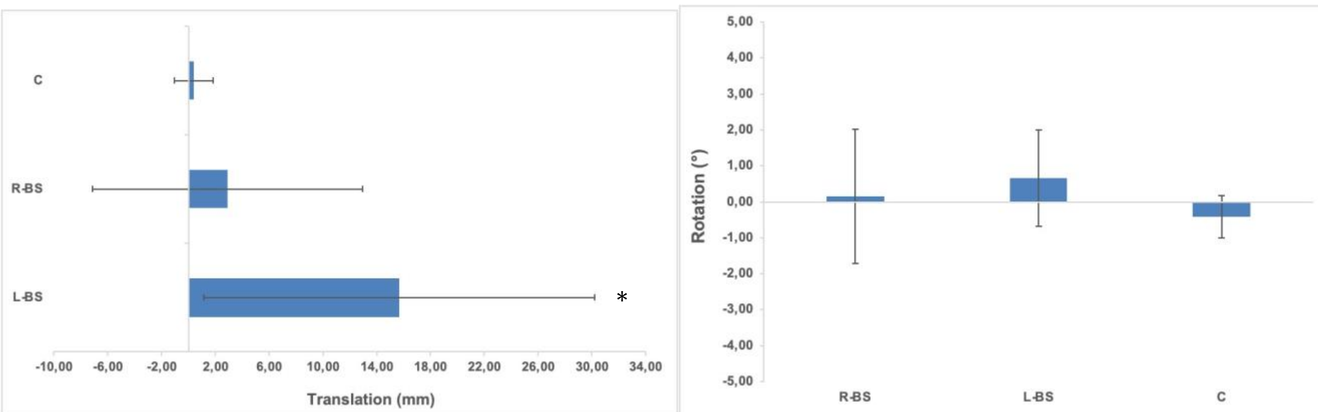

Figure 3. The SSA direction is reported for L-BS and R-BS patients and healthy controls (C) in the horizontal plane. * $p < 0.05$

The severity of the translational shifts in the horizontal plane was directly correlated to the importance of imbalances according to the PASS scale based on 36 points ($R^2 = 0.64$, Figure 4); a greater deviation of the SSA associated with more postural imbalances (aka a smaller score on the PASS scale).

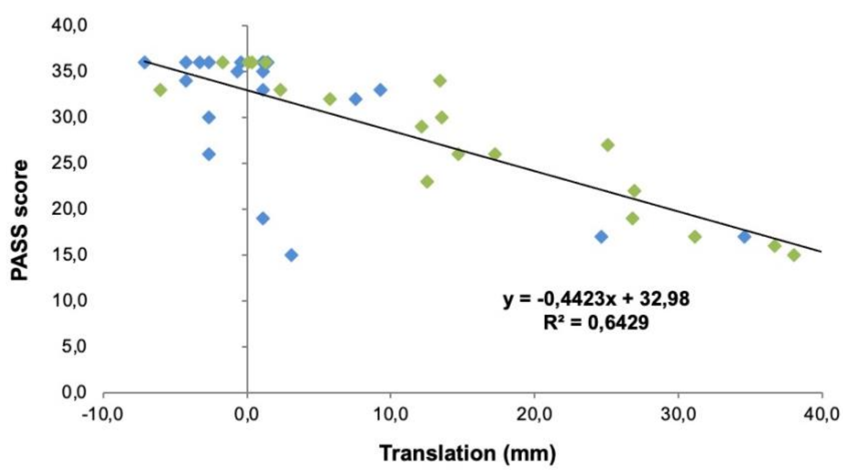

Figure 4. Relation between PASS score and deviation in translation of SSA.
The blue points represent the RB-S patients, and the green points represent the LB-S patients.

Lesions correlation analysis

The MRIcro and VLSM softwares demonstrated that the brain injuries followed a left-right axis in the brainstem (Figure 5A), with a cross at the pontine level (Montreal Neurological Institute (MNI) coordinates: x=-8, y=-19, z=-26). In the lower brainstem, errors in the straight ahead and postural instability, quantified by the clinical scale PASS, correlated with lesions on the left. In the upper brainstem, they were associated with lesions on the right. At the pons level, the location of the lesions suggests that some nuclei are more involved in postural disorders of the participants: the pontine nucleus, the medial lemniscus and the gigantocellular nucleus (Figure 5B).

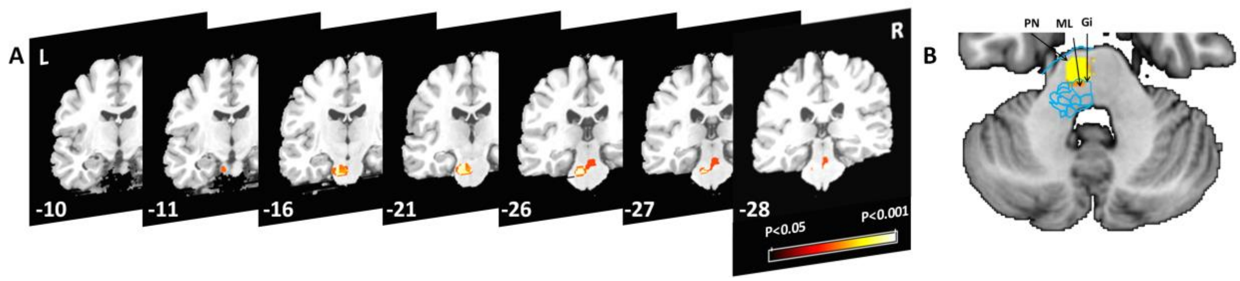

Figure 5. A) Correlation between the subjective straight-ahead shift and anatomical location of lesions in the brainstem in a color gradient. The axial sections include z coordinates between -18 and -10; B) The pontine nuclei is more involved in postural disorders of the participants. PN = pontine nuclei; ML = medial lemniscus; Gi = gigantocellular nucleus.

DISCUSSION

In this study, body representation was evaluated in patients who have suffered from a stroke located in the brainstem. For this, egocentric perception in the mid-sagittal plane was studied using the protocol of the SSA. The deviation to the right shown in patients of the L-BS group, but not in those of the R-BS group or C group, was due to a translation of the SSA, without any rotation effect, just like it was demonstrated in another study[20]. It was also correlated with a greater postural instability measured by the PASS scale. There was no significant difference between the R-BS and C groups for the task of the SSA or for evaluation using the PASS scale.

The estimation errors of the straight-ahead and imbalances reported by patients were associated with brain damage in the lower left part of the brainstem and in the upper right part, suggesting a pontine decussation. In this region, the pontine nucleus, medial lemniscus and gigantocellular nucleus were particularly affected by the strokes. Kirsch et al.[14] already suggested an involvement of these nuclei in a vestibular pathway decussating at the pontine level. In fact, recent studies[14,35] have shown the coexistence of ipsilateral and contralateral pathways between the vestibular nuclei and the vestibular cortex, with channels projecting through the posterolateral and posteromedian thalamus. This vestibular circuitry at the brainstem level forms a rope-ladder like structure. Using DTI tractography, Dieterich and al.[35] found a superior quantity of vestibular pathways leading to the right hemisphere. In fact, results of both these studies [14,35] suggest a structural and functional asymmetry of the vestibular apparatus and a vestibular dominance in the right hemisphere (at least in right-handers). This vestibular dominance of the non-dominant hemisphere had been demonstrated before[36]. Eguchi et al.[4] also found that vestibular symptoms after a stroke were more often associated with an infarction in the right hemisphere, more specifically in the vestibular cortical network, suggesting once again a vestibular hemispheric dominance. Furthermore, Dieterich et al.[35] mention that this asymmetry of the vestibular system in the brainstem contributes to the right hemispheric dominance of spatial cognition. Our study is therefore in line with the existing literature.

It remains to determine whether the asymmetry of representation is effectively the source of postural bias that patients develop, which remains the main hypothesis. Barrett[37] suggests that the assessment of the body representation would be a good marker to identify patients at high risk of falling. It would be interesting to introduce a reconditioning work focused on the perception of balance and body in patients after a stroke in the brainstem, to prevent them from developing postural disorders later. Early recovery of balance is essential for a quick recovery of independence in the activities of daily living and a less sedentary lifestyle. Indeed, proper gait and balance are important in reducing fall risks and improving independent mobility. In fact, a systematic review[38] showed that early intervention targeting balance and gait in stroke patients improved their balance and walking capacity. Although we are still lacking evidence of the maintain of these improvements in time, rehabilitation with aerobic exercises during the acute stroke period seems to be beneficial for patients and should be the target of the interventions. Additionally, trunk training seems to be important to consider as well during the recovery period after a stroke. Studies have shown that it can improve trunk performance and sitting balance[39–41] as well as standing balance and mobility[39,42] in stroke patients.

These results could lead to the establishment of a rehabilitation program of postural disorders, based on the correction of body representation. This representation in space requires the integration of vestibular, visual and somatosensory inputs. Several studies have shown that sensory stimulation has effects on postural support, probably by acting on the balance disorders secondary to spatial cognition disorders. Indeed, various studies have shown that sensory stimulation can improve the postural asymmetry of the subject[11,13,43] .

A recent study[44] based on the repetitive sensory stimulation by prismatic adaptation seems to confirm this hypothesis. This method involves re-educating the body representation in the peri-personal space using prismatic glasses that deflect light. When the subject performs a movement in the direction of an object, he can correct it in real time depending on the visual inputs he receives. Gradually, the information is integrated into the cortex and when the subject removes the glasses, he commits mirrored estimation errors of those he has developed with them. Progressively, cortical remodelling is done, correcting this asymmetry of representation and reducing the postural asymmetry in right brain damaged patients. The demonstrated efficacy of repeating stimulation by prisms in these patients suggest that this therapy affects the balance, while correcting disorders of spatial cognition in outer personal space.

Other types of stimuli also have effects on the representation of the body in space. Two techniques of proprioceptive stimulation vibrations were tested: the gluteus medius muscle vibration (GMV) seems to have a predominantly peripheral effect[45], and the neck muscles vibration (NMV) seems to have a central effect on the representation of the body in space[46]. The vibration of neck muscles can affect the relative position of the body in space, due to the activation of brain regions linked to body representation and orientation[15,47]. Proprioception muscles play a crucial role in body perception, due to their connections with the vestibular system and the oculomotor system[48]. The inputs coming from the neck muscles proprioceptive receptors, vestibular receptors and from the oculomotor system are involved in the object location relative to the body. Their stimulation appears to have a specific effect on the representation of the body in peri-personal space[24], since they produce a deviation of the SSA to the same side as the vibration does[49,50].

In conclusion, these results provide strong evidence that the vestibular system is involved in the representation of body orientation in space. They also support the hypothesis of changes in body representation after structural changes induced by brainstem lesions. Moreover, they open new perspectives for future studies on the body representation and extra-personal space representation in rehabilitation after a stroke.

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ANNEXE

PASS scale

2.4.6 Posture

2.4.6.1 Évaluation des performances posturales : le "Postural Assessment Scale for Stroke" (PASS)

Le PASS est validé et adapté à une utilisation préférentielle sur le plateau technique. Il nécessite une table de rééducation ou d'examen. Sont évalués à la fois le maintien et le changement de postures, en position allongée, assise et debout. Il est particulièrement adapté à l'examen du patient hémiplégique dans les premiers mois qui suivent la cérébro-lésion, y compris les plus atteints (contrairement à la plupart des autres scores validés).

Nom : Prénom : Date de l'ictus :

Côte Hémiplégique : Kinésithérapeute référent :

	J-30	J-50	J-70	J-90	J-110	Sortie
	le	le	le	le	le	le
1) Mobilité						
Couché sur le dos :						
Se tourne sur le coté hémiplégique						
Se tourne sur le côté sain						
S'assoit sur le plan de Bobath						
Assis sur le plan de Bobath :						
Se couche sur le dos						
Se lève						
Debout :						
S'assoit						
Peut ramasser un objet à terre						
TOTAL sur 21						
2) Equilibre						
Assis sans support						
Debout avec support						
Debout sans support						
Appui monopodal coté hémiplégique						
Appui monopodal côté sain						
TOTAL sur 15						
TOTAL PASS sur 36						

GUIDE DE COTATION

1) Mobilité

0 : ne peut pas
1 : peut avec aide importante
2 : aide modérée
3 : sans aide

2) Equilibre

Assis :

0 : impossible
1 : nécessite un support modéré
2 : tient assis plus de 10 secondes sans support
3 : tient assis plus de 5 minutes sans support

Debout avec support :

0 : impossible
1 : nécessite deux personnes
2 : aide modérée d'une personne
3 : ne nécessite que l'aide d'une main

Debout sans support :

0 : impossible
1 : peut rester debout au moins dix secondes sans support
(éventuellement de façon très asymétrique)
2 : peut rester debout au moins 1 minute sans support
3 : idem 2, peut en plus faire des mouvements amples du (des) membres supérieur(s)

Appui monopodal :

0 : impossible
1 : quelques secondes seulement
2 : plus de cinq secondes
3 : plus de 10 secondes

Référence :

Benaïm C. et al., 1999.