31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Reach to grasp kinematics and EMG analysis of C6 quadriplegic subjects

J. Jacquier-Bret, N. Rezzoug, J.M. Vallier, H. Tournebise, P. Gorce, *Member, IEEE*

Abstract—**The aim of the present study was to assess the kinematics and the muscular activity of the upper limb of subjects suffering from a spinal cord injury (SCI) at the C6 level during a grasping task. Data were compared to a control group composed of able-bodied subjects. The electrical activity of six major upper limb muscles and 3D motion of the arm were recorded. Results showed higher relative muscular solicitation for C6 patients especially for deltoïdus posterior and the pectoralis major and modifications of the range of motion of the corresponding joint angles. It appeared that, for C6 SCI subjects, the role of shoulder complex is highly relevant to initiate and control upper extremity movement, and so is important for their autonomy. Such data may be used to help clinician in decision making, e.g. for reconstructive surgery by musculotendinous transfer.**

I. INTRODUCTION

MOTION analysis may constitute an interesting way to study human functional capacities in many and various situations. Such data have found applications in different fields such as ergonomics or robotic assistance. Recently, this approach has been applied in the medical field to assess motor performance of patients during specific motor tasks, including activities of daily living [1]. In the presence of a spinal cord injury (SCI), especially at the C6 level, upper limb motions appear to be altered when executing basic daily life gestures [2], [3] due to a reduction or suppression of the activity of important upper-limb muscles. The absence of a voluntary contraction of the triceps brachii and more distal upper limb muscles (forearm and hand muscles) may constitute the major cause of the impairment. To compensate for this loss of functional capacities, C6 patients have to acquire new coordination patterns and motor programs [4], [5] especially during a period of rehabilitation.

J. Jacquier-Bret is with the HandiBio laboratory (EA 4322), Université du Sud – Toulon - Var, Avenue de l'Université BP 20132, 83957 La Garde Cedex, France (e-mail: jacquier@ univ-tln.fr).

N. Rezzoug is with the HandiBio laboratory (EA 4322), Université du Sud – Toulon - Var, Avenue de l'Université BP 20132, 83957 La Garde Cedex, France (e-mail: rezzoug@ univ-tln.fr).

J.M. Vallier is with the HandiBio laboratory (EA 4322), Université du Sud – Toulon - Var, Avenue de l'Université BP 20132, 83957 La Garde Cedex, France (e-mail: vallier@ univ-tln.fr).

H. Tournebise is the head of the reeducation and rehabilitation department at the Renée Sabran hospital, boulevard Edouard Herriot Giens, 83406 Hyères cedex 03, France (hubert.tournebise@chu-lyon.fr).

P. Gorce is the head of the HandiBio laboratory (EA 4322), Université du Sud – Toulon - Var, Avenue de l'Université BP 20132, 83957 La Garde Cedex, France (corresponding author phone: +33494142755; fax +33494142278; e-mail: gorce@ univ-tln.fr).

Practically, the recovery of a voluntary elbow extension has a direct impact on the patient independence. For example, the range of motion is increased or the propulsion in wheelchair and grasping actions, considered as the function that would the most improve their daily life [6], are facilitated. These qualitative results are supported by experimental studies based on upper limb motion analysis. With a multi directional reaching task, [7] showed firstly that quadriplegic patients with paralyzed triceps brachii are able to produce elbow extension by anticipating mechanical interaction coupling between upper limb segments. Secondly, authors suggested that the reactivation of active elbow extension by musculotendinous transfer lead to a stabilization of the elbow joint. This upper limb reconstructive surgery may ensure some elbow stiffness by co-activation with the antagonist flexor muscles and thus might improve the stability of the entire limb.

Such experimental studies have provided interesting data to the clinicians in order to develop new rehabilitation programs. For example, the reinforcement of the shoulder muscles [1] and a large variation of the conditions of motor exercise [7] were recommended. However, few data are available to help clinician for decision-making, especially for surgical intervention at the upper limb level. Indeed, the reanimation of the elbow extension with reconstructive surgery may be obtained by tendon transfer either from the deltoïdus posterior [8] or from the biceps brachii [9]. Actually, the choice of the muscle is based on a subjective evaluation of the capacities of the patient. Upper limb motion analysis during activities of daily living combining EMG and kinematics data may provide objective indications in favor of one muscle when surgery is considered. So, using a reach to grasp task, the aim of this work was to assess simultaneously the participation of specific upper limb muscles using a surface electromyography and the 3D motion of the arm to give insight into the movement reorganisation after a SCI at the C6 level and identify some parameters that may help the clinician in his choice.

II. MATERIAL AND METHOD

A. Subjects

Eight healthy subjects (178.7 ± 6.4 cm, 26.2 ± 5.0 years and 73.1 ± 8.8 kg) and five C6 quadriplegic patients (171.8 ± 8.6 cm, 39.6 ± 9.7 years and 78.2 ± 7.4 kg) right-handed male subjects volunteered to take part in the experiment. All SCI patients, staying at the Renée Sabran hospital, "*hospices civiles de Lyon*" for their rehabilitation program, presented a complete lesion at the C6 level according to the ASIA classification [10] since at least six months before the experiment. Each one was classified at the third level of international surgical classification. No one presented voluntary contraction of the right triceps. Moreover, none of the C6 subjects underwent a tendon transfer.

B. Experimental setup

A horizontal wooden table with a specific curved design was used during the experiment. SCI subjects were seated in their own wheelchair and healthy subjects in a standard one. The trunk was strapped to the back of the wheelchair to prevent trunk movements. An axis perpendicular to the frontal plane and passing through the center of the shoulder was drawn. The hand of the subject was placed on this axis, forearm resting on the table. This initial arm posture was marked to be reproducing across repetitions. The task consisted in grasping a low mass cubic object in polystyrene (side: 5.5 cm) placed at 40 cm on the drawn axis from the hand of the subject and bring it back to the starting position. Ten trials were performed.

Electrical activity of six major muscles of the upper limb (the upper part of the perctoralis major, deltoïdus anterior and posterior, the long head of the biceps, the triceps brachii, and the extensors carpi radialis) was recorded at 2500 Hz during the task using surface electromyography (EMG) (DT 9800-series, Data Translation, Marlboro, USA). The triceps brachii was analyzed for C6 patient to control the absence of activity. Before the session, a five seconds isometric maximum voluntary contraction (MVC) test was executed for each muscle. EMG activity and developped force (using a force sensor, TME 78 Orgeval, type: F501 TC, EM: 50daN, France) were simultaneously recorded. Three trials interspersed with five minutes of recovery were performed. The trial with the highest muscular force was selected. Then, EMG data of each trial were normalized by the EMG at the MVC, high-pass filtered by a numerical zero-lag Butterworth 10th order filter at 20 Hz, second full-wave rectified and third, low-pass filtered with a third order Butterworth filter at 5 Hz to obtain the linear envelop of muscular activity. To study the EMG activity, muscular activation was computed for each muscle and each trial as the integral of the linear envelop iEMG [11].

Synchronized with the EMG signals, the movement of the scapula-clavicula, the arm, the forearm, and the hand, was recorded with four Flocks of Birds sensors (FoB, Ascension technologies inc., Burlington VT, USA). Nine joint angles were evaluated at each step of the movement from the local FoB coordinate systems: clavicular protraction-retraction, clavicular depression-elevation, glenohumeral (GH) plane of elevation, GH elevation, GH axial rotation, elbow flexion-extension, wrist pronation-supination, wrist radial-ulnar deviation, and wrist flexion-extension. Joint angles were all zero at the anatomical referential posture and were computed using the method proposed in [7].

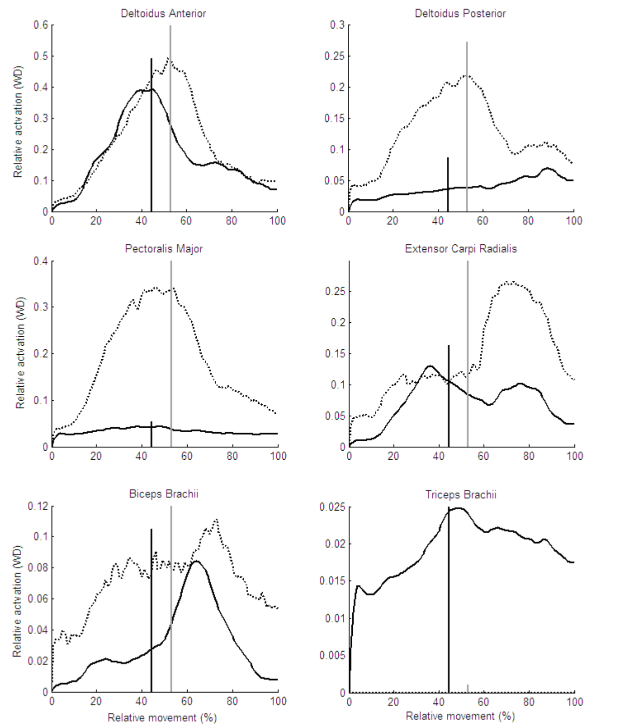

Fig. 1. Mean activation pattern of the six considered muscles during the reach-to-grasp task. The Solid line is for healthy subjects and the dotted line is for C6 subjects. Vertical lines represent the relative instant of grasping. The black line is for healthy and the grey line is for C6 patients. Please note that the scales on the vertical axes are different for each muscle.

To compare all collected data, the movement duration was normalized using a cubic spline resampling (101 samples): 0% of the duration corresponds to the movement onset and 100% corresponds to the return to the initial arm position. A non-parametric Mann-Whitney test was used to compare the iEMG for each muscle and the mobilized range of joint angles between the healthy and SCI groups (Statistica 7.1., Statsoft, Tulsa, OK, USA). Difference was considered significant for $P<0.05$.

III. Results

A. Surface electromyography

The normalized mean activation profiles of the six considered upper limb muscles are presented in figure 1. Higher relative iEMG values were found for pectoralis major and deltoïdus posterior for SCI patients (21.37±20.04 versus 3.26±3.52 and 14.76±13.66 versus 3.81±3.68, $p<0.05$). In contrast, the activation time profile of the biceps brachii and the deltoïdus anterior appeared similar for the two groups (Mann-Whitney test: NS).

Activation values triceps brachii for C6 SCI subjects were not reported because no detectable EMG activity was recorded for this muscle. Contrary to the observed mean activation pattern of the extensor carpi radialis, no difference was found between able-bodied and C6 subjects (Mann-Whitney test: NS). Note that during the task, all the recorded muscles (except for the triceps of the SCI patients) were activated throughout the movement.

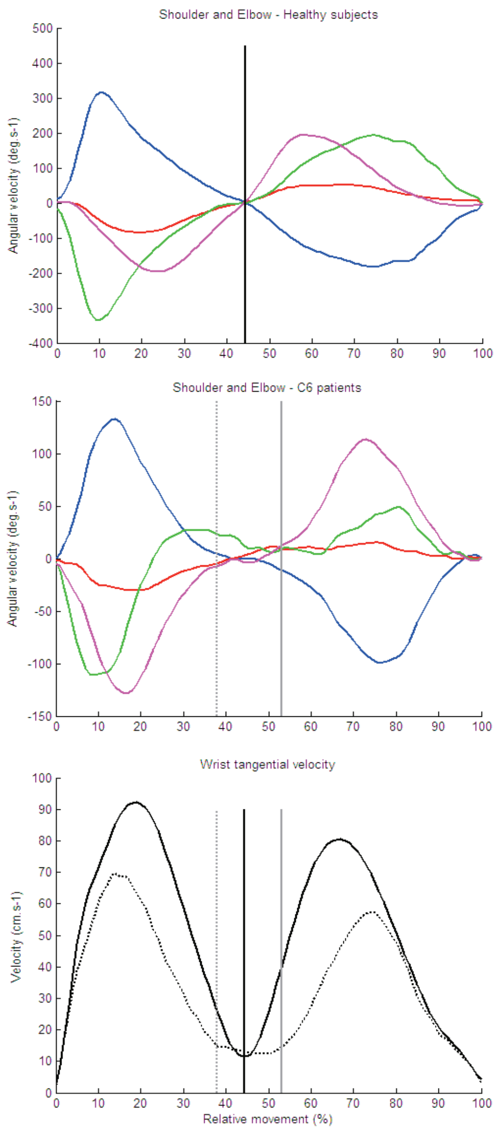

Fig. 2. Evolution of thoraco-clavicular and shoulder joint angular velocities associated with the wrist velocity during the reach-to-grasp task according to normalized time. The vertical bold line corresponds to the instant of grasping, the black vertical line corresponds to the healthy subjects and the grey line is for C6 subjects. *Top panel:* angular velocity of the shoulder plane of elevation (blue), the shoulder elevation (red), the shoulder axial rotation (green), and the elbow flexion-extension (magenta) for the healthy subjects. *Middle panel:* C6 subjects. Values between the bold and the dotted vertical grey lines are for angular velocities lower than 5% of the maximal angular velocity. *Bottom panel:* amplitude of the wrist tangential velocity.

B. *Kinematics*

When regarding the range of motion during the task, significant differences between the two groups were found for five of the nine measured joint angles. Indeed, C6 patients presented lower values for GH axial rotation and elbow flexion-extension. On the contrary, they presented higher range for clavicular protraction-retraction, clavicular elevation-depression, and wrist radial-ulnar deviation (see TABLE I). A particular result was observed for the wrist. Even if the range of motion during the task was not different between the two groups, statistical analysis revealed that C6 patients kept their wrist flexed during the whole movement (mean: 19.55 degrees; range: 0.24 to 38.85 degrees) whereas control subjects used wrist extension to perform the grasping task (mean: -12.05 degrees; range: 8.20 to -32.29 degrees, $p<0.05$).

When considering the angular velocity of the shoulder plane of elevation, the shoulder elevation, and the elbow flexion-extension, C6 subjects presented a stabilisation of values during 15.12±4.99% of the relative movement time before the grasping (range: 37.98 to 53.10%), keeping a wrist tangential velocity at a stable value, about 20% of the maximal speed (figure 2, middle and bottom panels).

Finally, control subjects performed the grasping of the object earlier than C6 patients in relative movement time (44.46±1.94% and 53.10%±4.99% respectively, $p<0.01$). However, no difference was found for the absolute movement time between the two groups.

IV. Discussion

This work aimed at assessing the upper limb motor capacities of patients presenting a SCI lesion at the C6 level. The study was based on motion analysis in order to describe the muscular activation patterns and the evolution of involved joint angles during a grasping task.

The main result was the higher level of relative activation of the pectoralis major and the deltoïdus posterior measured for the quadriplegic patients. As illustrated in figure 1, these two muscles presented a peak of activation during the transport phase occurring at the grasping instant, followed by a decrease until the end of the movement, i.e. the return to the initial position. In addition, higher values of muscular activations are correlated with a fixation of the shoulder posture (low values of shoulder angular velocity, figure 2, middle panel). This phenomenon was not observed for the control group. Finally, modifications of range of motion were observed at the shoulder, the elbow, and the wrist level between the two groups.

Considering the spinal cord lesion and the associated neurological impairments, SCI patients have to operate a modification of the movement realization both at the kinematics and the muscular levels [5]. These findings are in agreement with a previous study conducted by [4] in which motor patterns during a planar reaching performed after a cervical SCI were presented. The proposed results suggested that SCI subjects were able to produce reaches with typical global kinematics features (i.e. straight finger path, bell-shaped velocities) but with a different muscle activation patterns than control subjects. Only the shoulder agonist muscles were activated for reaching in all directions unlike able-bodied persons who used a combination of agonist-antagonist contractions at each joint. In the present work, the deltoïdus anterior, the deltoïdus posterior and the upper part of the pectoralis major were simultaneously activated. These three muscles are principally involved in the elevation of the humerus, with a complementary action of adduction for the pectoralis major. This observation during a 3D reach-to-grasp task is similar to the 2D results presented by [4].

Due to cervical lesion, SCI subjects may develop a new scheme of coordination by using preferentially primary function of each involved muscles and/or muscle groups. However, the activation level of the humeral depressor muscles (especially the lower part of the perctoralis major and the latissimus dorsi) was not considered. Previous studies using invasive EMG analysis suggested a significant weakness of this muscle group especially due to the level of their innervation below the lesion (C6, 7 and 8) during activities of daily living [1] or weight-bearing activities [12]. So, the transport phase of the arm from an initial position, i.e. the displacement of the hand near the target, performed by SCI subjects seems to be the result of a regulation of the shoulder elevator and adductor muscle contractions combined to the effect of gravity rather than a co-activation of agonist-antagonist muscle groups.

In this condition, the role of the deltoïdus posterior in the execution of the movement appeared important and a tendon transfer from this muscle may imply a weakening of the shoulder joint stability and may lead to an increase of the muscular solicitation at the shoulder level and indirectly an increase of the difficulty to perform the task.

Results observed for the elbow joint may not be in favor of a tendon transfer from the biceps brachii. Indeed, the steady-state of activation values observed for this muscle during the main part of the transport phase (20-65% of the relative movement duration) suggested a control of the arm extension only by control of the elbow flexor muscle. As suggested by [7], SCI subjects initiate the elbow extension by the exploitation of the mechanical interaction coupling between upper limb segments. In other words, SCI patients may produce higher relative level of contraction at the shoulder to induce interaction coupling with the elbow and so to generate a passive extension of the forearm. Then, the biceps brachii may act as a brake to control the extension and to compensate for the absence of the triceps brachii during the first phase of the reach-to-grasp movement. However, the capacity of flexion at the elbow level is kept for C6 patient. This function is assumed by two other muscles, the brachialis and the brachio-radialis. Also, the transfer of the biceps brachii to the elbow extension function may present fewer constraints than the deltoïdus posterior. In conclusion, results suggested that proximal joints (i.e. the shoulder complex) are highly involved in the upper limb motion and their weakness could be harmful for the autonomy of C6 patient.

Upper limb motion analysis allows the assessment of motor capacities and the movement reorganization after SCI and data could be used to help clinician in decision making, e.g. for tendon transfer surgery.

References

[1] J. K. Gronley, C. J. Newsam, S. J. Mulroy, S. S. Rao, J. Perry, and M. Helm, “Electromyographic and kinematic analysis of the shoulder during four activities of daily living in men with tetraplegia”, *J. Rehabil. Res. Dev.*, Vol. 37, n° 4, 2000, pp. 423-432.

[2] R. D. Welch, S. J. Lobley, S. B. O'Sullivan, and M. M. Freed, “Functional independence in quadriplegia : critical levels”, *Arch. Phys. Med. Rehabil.*, Vol. 67, 1986, pp. 235-40.

[3] G. M. Yarkony, E. J. Roth, A. W. Heinemann, and L. Lovell, “Rehabilitation outcomes in C6 tetraplegia”, *Paraplegia*, Vol. 26, 1988, pp. 177-85.

[4] G. F. Koshland, J. C. Galloway, and B. Farley, “Novel muscle patterns for reaching after cervical spinal cord injury: a case for motor redundancy”, *Exp. Brain. Res.*, Vol. 164, 2005, pp. 133–147.

[5] Y. J. M. Janssen-Potten, H. A. M. Seelen, H. M. H. Bongers-Janssen, and L. H. V. van der Woude, “Assessment of upper extremity muscle function in persons with tetraplegia”, *J. Electromyogr. Kines.*, Vol. 18, 2008, pp. 516–526.

[6] G. J. Snoek, M. J. Ijzerman, and H. J. Hermens, “Survey of the needs of patients with spinal cord injury: impact and priority for improvement in hand function in tetraplegics”, *Spinal Cord*, Vol. 42, 2004, pp. 526-532.

[7] G. Hoffmann, I. Laffont, S. Hanneton, and A. Roby-Brami, “How to extend the elbow with a weak or paralysed triceps? Control of arm kinematics for aiming in C6-C7 quadriplegic patients”, *Neuroscience*, Vol. 139, 2006, pp. 749-765.

[8] E. Möberg, “Surgical treatment for absent single-hand grip and elbow extension in quadriplegia. Principles and preliminary experience”, J. Bone. Joint. Surg. Am., Vol. 57, 1975, pp. 196-206.

[9] E. Zancolli, “Structural and dynamic bases of hand surgery”, in *Quadriplegia*, E. Zancolli, Ed. Philadelphia: J. B. Lippincott, 1979, pp. 263-283.

[10] American Spinal Injury Association (ASIA), “Reference manual for the International standards for neurological classification of spinal cord injury”, *American Spinal Injury Association*, Chicago, 2000, pp.1-23.

[11] A. Bonnefoy, N. Louis, and P. Gorce, “Muscle activation during a reach-to-grasp movement in sitting position: Influence of the distance”, *J. Electromyogr. Kines.*, Vol. 19, 2009, pp. 269–275.

[12] M. L. Reyes, J. K. Gronley, C. J. Newsam, S. J. Mulroy, and J. Perry, “EMG analysis of shoulder muscles of men with low-level paraplegia during a weight relief raise”, *Arch. Phys. Med. Rehabil.*, Vol. 76, 1995, pp. 433-439.