PERFORMANCE EVALUATION OF THE NEW OTTO BOCK “DynamicArm” BY MEANS OF BIOMECHANICAL MODELLING

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1. INTRODUCTION

Through infra-red motion analysis systems it is possible to acquire the 3D joint kinematics of a patient while performing every day activities. These data, combined with a biomechanical model of the anatomical structures under investigation and clinical rating scales, can form the basis for an objective assessment of the patient motor ability. When the subject acquired is an amputee fitted with a new prosthetic arm, the information provided can be useful not only for the practitioner but also for the prosthesis designer. The aim of this work is to give an example of this kind of clinical/technology assessment, presenting the results obtained for a young trans-humeral amputee fitted with a prototype of the new Otto Bock DynamicArm. In particular, the analysis intended to quantitatively evaluate: 1) the performances of the Otto Bock arm, and in particular of the electromechanical elbow, when controlled in-vivo by the patient EMG signals; 2) how the patient controls the prosthesis, in order to identify critical movements and prevent possible disorders; 3) if the new prosthesis increases the patient abilities.

2. MATERIAL AND METHODS

2.1 The new Otto Bock DynamicArm

The 12K100 DynamicArm is a myoelectrically controlled and electromotively powered elbow joint for the fitting of upper arm amputees up to very distal trans-humeral amputation level (theoretically up to 4cm less the natural length of the arm). The main advantages of the DynamicArm are: 1) high lifting and holding force (with lift arm set to 305 mm: lifting force=60N; holding force=230N); 2) minimal lift time 0.5s depending on forearm length and terminal device used; 3) natural free swing characteristics; 4) low noise level and no internal noise in free swing; 5) integrated lithium-ion battery with capacity for one day; 6) appealing exterior. The DynamicArm and hand prosthesis is controlled by electrodes, linear control elements, switches or a combination thereof. The CPO can adjust to the individual patient via Bluetooth\textsuperscript{\textregistered} technology. The electric elbow can be locked or unlocked even with a switched-off DynamicArm or with an empty battery by operating the pull-cable from any position, even under load. An AFB (Automatic Forearm Balance) flexion tool stores the gravitational energy released when extending the arm and uses it for flexion. The battery operating time is thereby considerably increased, hoist time shortened. The vario drive allows for harmonic movements and high lifting forces.

2.2 Subject description and prosthesis set-up

The subject involved in the present tests (after giving his informed consent), was a young adult (initials GF) who underwent a first proximal trans-humeral amputation in 2003 due to a work-related trauma. GF received a first myoelectric prosthesis with threshold control in 2004, and after few months he was given the first version of the Otto Bock arm with proportional control, which he was immediately able to manage. For both he received proper
training. GF controlled the elbow flexion and extension with contractions of the trapezius and deltoid, respectively. The length from the Otto Bock elbow axis of rotation to the load carrying position of the hand was 365mm. Since different patients will have different performances depending on their lever arm and hand type, the performances of the Otto Bock elbow were set to a medium level (in terms of maximal excursion and velocity) to reasonably report a mean performance.

2.3 Clinical rating scale assessment
GF ability in controlling the threshold and the Otto Bock prostheses was clinically assessed at the end of the respective training periods through an interview and using the ABILHAND rating scale [1].

2.4 Motion analysis protocol
GF was acquired with a VICON 460 stereophotogrammetric system (Vicon Motion Capture, Oxford, UK) with 6 video cameras, while performing 5 elbow flexion-extension trials with different loads on the hand: 0Kg, 0.52Kg, 1Kg, 2Kg, 3Kg. For every trial, at least two consecutive flexion-extension cycles were repeated. GF was instructed to always perform the movement as fast as possible.

To analyze the electromechanical elbow performances, the relative motion of the forearm with respect to the third distal had to be tracked. Since GF engaged the elbow with contractions of trapezius and deltoid, possible critical movements could arise from excessive motion of the head and shoulder girdle, leading to early deterioration of the sterno-clavicular, acromio-clavicular and scapulo-thoracic joints (hereinafter referred together as the “shoulder”), and cervical rachis problems. Given these considerations, twenty retro-reflective markers were attached on the head, thorax, socket, third-distal and forearm, thus defining an open kinematic chain with 7 active degrees of freedom (Figure 1a,b), associated to the neck, shoulder and elbow joints. To define the mobility of these joints, a system of reference (SoR) had to be defined for each segment. For the head, thorax and shoulder girdle these were obtained through the “calibration” of relevant anatomical/prosthetic landmarks with respect to the correspondent cluster of markers [2-5]. For the definition of the third-distal and the forearm SoR, we combined the use of well-identifiable landmarks, with a functional, optimisation-based method [6], which enables to compute the real axis of rotation of the elbow (flexion-extension) and of the hand (pronosupination) [7]. Joint angles were then obtained decomposing the relative orientation of adjacent segments using appropriate sequences of Euler angles: flexion-extension (FL-EX)

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Figure 1a,b  a) Marker-set used: markers on the left acromion and the hand are used for visualization purposes only. Not visible in the figure: markers on the 7th cervical and 8th thoracic vertebra and on the left and posterior part of the head; b) kinematic model of the amputee with the prosthesis; abbreviations are only given for the joint angles analysed in the paper (see text for details).
and prono-supination for the elbow, flexion-extension, lateral flexion (LF) and axial rotation for the neck and protraction-retraction (PR-RE) and elevation-depression (EL-DE) for the shoulder.

2.5 Data analysis
Using the shoulder angles and their first derivative, we identified in each trial the following phases: elbow flexion, transition from flexion to extension, elbow extension. In each phase the head, shoulder and elbow patterns were analyzed in terms of excursion and velocity.

3. RESULTS AND DISCUSSION

3.1 Clinical rating scale assessment
GF reported a generalized satisfaction in the use of the new prosthesis. In particular he stressed the possibility to lift heavy loads with the prosthetic arm. The comparison of the ABILHAND post-training results with the threshold and with the Otto Bock prosthesis, showed with this latter an improvement in the feeding and dressing issues, which changed from difficult to easy. These results appear to be related to the Otto Bock proportional control.

3.2 Elbow performance
Elbow flexion and extension patterns for the different loads tested are shown together in Figure 2. Given the high level of repeatability found in the gesture, only one representative curve among the repetitions is reported for every load. The mean range of elbow flexion-extension observed was 115° (coefficient of variation: 4%), which decreased of about 11° changing the load from 0Kg to 3Kg. The minimum elbow extension ranged from 2° (1Kg) to 8° (0Kg), while the maximum flexion from 112° (3Kg) to 126° (0Kg). The range measured is thus smaller than that of an able-bodied subject (140°-150°) but, for light loads, appears to be adequate for most feeding activities [8].

The maximal and mean velocities reached in flexion were 145°/s 77.4°/s, respectively, when no load was applied on the hand; these velocities decreased to 32°/s and 14.8°/s for 3Kg. The maximal and mean velocities in extension were 220°/s and 88°/s respectively, for 0Kg; these velocities decreased to 31°/s and 19°/s for 3Kg. From the patterns reported it appears that the elbow behavior can be roughly subdivided in two
groups: from 0Kg to 1Kg, in which the elbow gave its best performances with limited degradation, and 2Kg-3Kg, in which a noticeable lengthening of motion duration could be observed, both in flexion and extension.

3.3 Subject movements for prosthesis control

The macroscopic effects of the trapezius (for flexion) and deltoid (for extension) contractions are reported in Figure 2: the elbow flexion appears to be activated by a shoulder elevation and retraction, while the extension by a shoulder depression and protraction. An exception was the slight girdle protraction for elbow flexion with 2Kg and 3Kg, which was however followed by a higher protraction for extension. Shoulder motion usually ranged from 11° to 8°, both for elevation-depression and protraction-retraction, generally tending to decrease with the increase of the load. An explanation for this result can be found observing that heavier the load, higher the muscle force required to move the shoulder girdle against gravity. Since the EMG level for maximal performance is fixed, this means that with heavier loads the motion required to reach this level is smaller. While the shoulder motion tended to decreases, with increasing loads the duration of the contraction tended to increase, almost doubling from 0.52Kg to 2Kg. The elbow flexion-extension was also followed by 8°-12° of lateral flexion of the head toward the shoulder during flexion. These frequent, incongruous, asymmetric and repetitive gestures appears to be all risk factors for potential shoulder and cervical rachis cumulative trauma disorder syndromes, with mechanical irritation of the tendinous and peritendinous structure and chronic muscular fatigue. This latter problem may also result in a decrease in the quality of the EMG signals acquired by the prosthesis sensors. A focused rehabilitation (e.g. relaxant masotherapy, physical exercises for a correct articulation and stretching) may help in prevention. Further analyses are required to draw definitive conclusions.

4. CONCLUSIONS

The aim of this paper was to quantitatively assess the performances of a prototype of the new Otto Bock DynamicArm in-vivo when directly controlled by an amputee. The Otto Bock arm proved state-of-the-art performances in terms of liftable loads, angular range and velocity, with general satisfaction of the patient. Considering the patient into the measurement loop, gave the possibility for a kinematic analysis of his movements, bringing in evidence potentially critical motor strategies. Future efforts will be intended to confirm these observations on the patient examined and on a representative population of amputees.

5. REFERENCES