The Effect of Prolonged Strenuous Activities on Patient Socket-Stump Kinematics, Kinetics and Cardiopulmonary Response

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Abstract: It has been shown that as the level of the amputation moves proximally, the walking speed of the individual decreases, the biomechanical efficiency decreases and the oxygen consumption increases [1]. In addition, strenuous activities influence further this efficiency and are related not only to the subjective perception of discomfort or pain, but also to the measurable amount of displacement and deformation that occurs inside the prosthetic socket during motion. For this study, measurements of internal three-dimensional (3D) residual stump skin-socket kinematics by use of high accuracy Dynamic Roentgen Stereophotogrammetric Analysis (DRSA) [2] were combined with cardiopulmonary patient monitoring and direct prostheses kinetics assessment (wireless Intelligent Prosthetic Endoskeletal Component System-iPecs™) in ten trans-tibial (TT) amputees for a course of continuous strenuous Activities of Daily Living (ADL). This protocol established a baseline for reliable TT outcome assessment associated with strenuous activities.

Methods: Ten trans-tibial amputees (Age: 61.2±11.9 years, body mass: 92.2±22.3 kg, body height: 162 cm ± 7 cm, Stump length: 16±3 cm) wearing both total surface bearing and Elevated vacuum socket designs volunteered for this study approved by the University of Wisconsin Milwaukee IRB. Testing was conducted with patients wearing the two different socket designs in accordance with the *MOVE Center Strenuous activities protocol* (MCSA) which consists of three parts that iterate the performance of a number of tasks, pain assessments and completion of a series of questionnaires as follows: **Part I** (1) completion of functional assessment questionnaires (*Prosthesis Evaluation Questionnaire* [3] and *Short Form-36* [4]); (2) anthropometric measurements and preparation of the patient (marker placement etc.); (3) performance of three trials of the following dynamic strenuous activities inside the DRSA image space: a) sudden stop, b) stepping-down from stair. Subjective assessment of pain/discomfort (Visual analogue pain scale) are recorded at the end of every trial. Synchronous continuous measurements include direct prosthesis kinetics with the iPecs wireless gait instrumentation (College Park Industries, MI), speed, distance travelled and cadence measurement and Cardiopulmonary exercise testing (CPET), all with wearable wireless devices (POLAR RS800CX Electro Inc., NY, and Oxycon Mobile portable metabolic system, CareFusion CA). **Part II (12 steps):** Each patient performs consecutively and with no interval the following 12 tasks (Fig. 1): 1) Getting up from a chair (no arm rests); 2) Walking (5m) and open door inwards (t_0); 3)Walking (10m) and open door outwards (t_1); 4)Walking (5m) and open door inwards (t_2); 5) 200 m walking on running track-in the first 100m a suitcase is carried (4kg) and two obstacles (23cm in height x 15 cm in width) are overcome at the end of the 50m and 150m line (t_2- t_7); 6) open a door outwards (t_7) and walking (30m) then open door inwards; 7)Picking up an object from the floor (pencil/keys) (t_8); 8)Walking down 22 stairs without handrail assistance (t_9); 9)Walking up 11 stairs without handrail; 10)Walking up 11 steps with handrail; 11)the patient unassisted lays down on the floor on his back and gets up to the erect position again (t_{10}); 12) Walking (50m) and open door outwards (t_{11}). **Part III:** Repeat of step 3) from PART I. During the MCSA protocol, subjective estimates (grading) of pain/discomfort is acquired during every task (several times during the prolonged tasks) of PARTS I, II and III. All data was averaged and analyzed by a Wilcoxon Signed Ranks test.

Figure 1. *(a) TTA patient performing strenuous task in the DRSA lab. The patient is wearing the elevated vacuum socket (f) which is instrumented with the iPecs™ wireless direct kinetics (force - moment) measurement device (c) and the cardiopulmonary assessment device (OXYCON), the POLAR monitor with shoe cadence-speed-distance-sensor (d). Note the number of radiopaque markers placed in the socket, liner and skin in one of the DRSA camera views (e).*

Results: The average bone-pistoning during the step down task was found to be significantly different between before (PART I) and after (PART III) the course of strenuous activities in the X and Y directions (p=0.05) for the TSB and EV sockets. Similarly, the average displacement (in all X,Y,Z directions) of all the proximal skin marker pairs, the average acceleration of all proximal skin deformation (all directions), the median of velocity of all distal skin deformation were also significantly different between the two conditions (before and after the course for both socket types) (p=0.05). Analysis of the direct prosthesis forces and moments measured by the iPecs revealed significant differences between the two socket types (p=0.05) for the whole 14 station circuit of PART II in the Z direction (vertical) of forces and in all X,Y and Z directions for moments (Fig. 2). Three patients complained about pain during stations t12 and t14 (stair tasks). Upon removal of the socket at the end of the test the clinician indicated the onset of a blister and a large erythema at the stump.

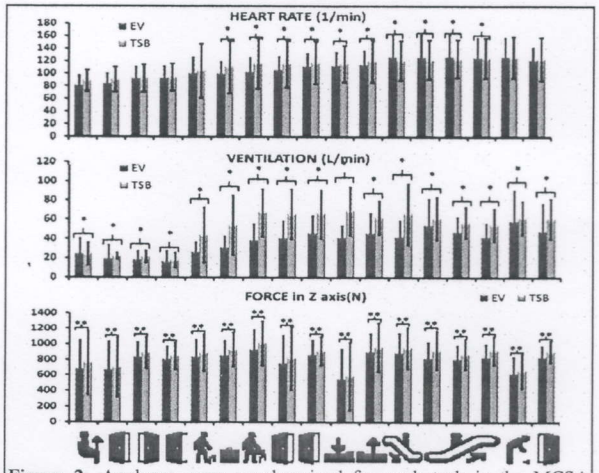

Figure 2: Analyses were synchronized for each task in the MCSA protocol. Heart rate (top) variability between tasks (abscissa) and significantly different responses due to EV or TSB socket designs. Similar response in ventilation (L/min) (middle) that can be associated with overall energy expenditure. Vertical prosthetics forces (bottom) as measured by the iPecs device during the protocol. Statistical differences between the two socket designs are significant at p=0.05 level.

Discussion: The protocol presented here employs a synchronous assessment of a large number of endogenous and exogenous key mediating socket-patient performance parameters using several wearable devices (CPET, direct kinetics and temporal measures) along with high accuracy DRSA socket-stump kinematics. This multitude of measurements revealed the detailed influence of socket design on strenuous ADLs. This protocol is critical in understanding socket behavior in prolonged strenuous ADLs in an effort to optimize prosthetic outcome measures in the community. **References:[1]** Michael WJ, et.al. editors. AAOS: Mosby Inc-Hardcover, June; 2008; **[2]** Papaioannou G, et. al. Assessment of--//--Analysis. JPO. 2009;22(1):1-15 **[3]**Legro MW, et. al. Prosthesis--//--of life. Arch Phys Med Reh.1998;79(8):931-8. **[5]**Hanspal RS, et. al. Prosthetic--//--score. Dis. & Rehab. 2003;25:1278-80.

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