Energy expenditure during rest and ADL increased by electrical stimulation-induced leg muscle activation

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***Abstract*— Obesity, increasingly common in individuals with spinal cord injuries (SCI), is for a large part due to an inactive lifestyle and a markedly lower resting energy expenditure (EE) as a result of the paralyzed muscle atrophy. A possible contribution to a solution is by increasing EE by electrical stimulation (ES)-induced activation of the paralyzed muscles. The purpose of this study was to evaluate if ES-induced muscle activation can be used during daily activities to increase EE. Nine men with a chronic SCI (C4/5-T11; ASIA A-C) performed 3 standardized daily activities for 30min each: lying on a bed (L), sitting in a wheelchair reading a book (S), and submaximal wheelchair propulsion on a treadmill (WC) while wearing a garment with built-in electrodes. During 20min of each activity, gluteal, hamstring, and quadriceps muscles were simultaneously activated using ES (50Hz) at individually adjusted comfortable current amplitude levels. EE was derived from oxygen uptake measurements using a portable gas analysis system. ES-induced activation was well tolerated by all participants and did not hinder the tasks performed. EE during L, S, and WC with ES (416±133, 375±70, 673±187 kJ/hr, resp.) was higher ($p<0.05$) than without ES (342±81, 318±38, 617±177 kJ/hr). This suggests that ±3-4 hr/day of activation is needed to counteract the average 182 kJ/day excess caloric intake found in SCI (De Groot 2010). In conclusion, ES-induced paralyzed muscle activation markedly increases EE during daily activities in SCI and might therefore be a potential way to help counteracting the development of obesity.**

I. INTRODUCTION

Obesity, increasingly common in individuals with spinal cord injuries (SCI), is for a large part due to an inactive lifestyle and a markedly lower resting energy expenditure (EE) as a result of the paralyzed muscle atrophy. The higher risk of becoming overweight or obese is reflected in a significantly higher prevalence compared to the healthy population. Moreover, obesity is found to be related to other secondary health complications such as diabetes and coronary heart disease and a concomitant increase in medical costs, which are already extremely high in adults with SCI [1]. Therefore, it is of utmost importance to reduce obesity by managing a balance between the energy intake and energy expenditure in people with SCI.

On average, the body mass index (BMI) of adults with SCI increases by 0.55 each year [2]. When converted to weight gain for an average man of 1.80m, this corresponds to a mass gain of about 1.8kg every year. To counterbalance this weight gain, either energy intake should be lowered or energy expenditure (EE) increased. Because people with SCI expend 860-2100kJ less per day than individuals without SCI [3], only almost extreme diets could compensate for this, at the same time increasing the risk of malnutrition [4]. Therefore, increasing EE might be a healthier way to maintain a well-balanced energy balance. To counteract the 1.8-kg weight gain each year, an increase of ±182 kJ per day seems needed.

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Such an increase in EE might be realized through upper-body exercising, but not everyone is capable of doing this. In these cases, electrical stimulation-induced muscle activation is a potential additional way to increase energy expenditure. By electrical stimulation (ES) of the normally inactive muscles below the lesion, these paralyzed muscles can now contribute to a higher EE. ES cycling, for example, seems to be an effective way of exercise. However, Perret et al. [5] concluded that an average of 4-8 hrs of ES-induced cycling per week would be needed to reach the recommended EE, making it a time consuming and hardly feasible option. Less time consuming would be ES-induced muscle activation during daily life. It is not clear yet, however, if ES during daily activities is feasible, to what extent it increases EE, and how long ES should be applied during daily activities in order to balance energy intake and EE in people with SCI. Therefore, the present study was designed to investigate whether ES of the upper legs during daily activities is feasible and if it results in an increase in EE expenditure in people with SCI.

II. METHODS

A. Participants

Nine men with an ASIA A, B or C lesion (C4-T11; TSI >6 months) participated in this study after providing informed consent. Participants were included if stimulating the muscles resulted in clear tetanic contractions. Exclusion criteria were current pressure ulcers, severe cognitive and/or communication disorders, flaccid paralysis, intolerance for ES, and a history of autonomic dysreflexia during ES. This study received approval from the Medical Research Ethical Committee of the Vrije Universiteit Medical Center.

B. Design

Participants visited the research laboratory once. While wearing a custom-built garment with built-in electrodes, they performed 3 standardized 30-min ADL tasks. with and without ES. Because ES results in muscle fatigue, which may influence EE, this fatigue was monitored by measuring the seating pressure and the size of the muscle contraction. To indicate the usability of the garment (ES shorts), the participants filled in a custom questionnaire.

C. Activities of Daily Living

The participants performed 3 ADL tasks, i.e. lying (L), sitting while reading a book (S), and submaximal wheelchair propulsion on a wide treadmill at a comfortable velocity (WC). Each task lasted 30 min, the first 5 min without ES, followed by 20 min of ES and another 5 min without. Two participants did not perform the wheelchair task, as they were using a motorized wheelchair. To simulate realistic performance of daily activities, participants were not instructed to sit or lie as still as possible, but to perform the task as they normally would, but without talking.

D. Electrical Stimulation

ES was applied by specially developed lycra shorts with built-in electrodes (Axiobionics, Ann Arbor, MI, USA), connected to a portable stimulator (Neuro-Pro 8 channel, Berkelbike BV, The Netherlands). The ES shorts can be unfolded completely and secured with a Velcro strap, making them easy to put on. The flat embedded surface electrodes were situated on the proximal part of the gluteal muscle, halfway down the hamstring area and on the middle part of the quadriceps. In this way, the participants did not sit on the electrodes. The portable stimulator was strapped to the participant's waist and hydrogel (Parker Aquasonic® 100) was used as conductor between the electrodes and the skin. To provoke tetanic contractions, the muscles were stimulated simultaneously at 50 Hz and a 1-4 duty cycle (1s stimulation, 4s rest). The current amplitude was individually set at the highest suitable level by increasing the amplitude in 5-10 mA steps to a maximum before each participant experienced discomfort such as pain, irritation or difficulties with holding their sitting or lying position.

E. Outcome measures

EE was calculated based on oxygen consumption measured by open-circuit spirometry (COSMED K4b2, Italy). Prior to every measurement, gas and volume calibration was performed. Mean EE without ES was calculated over the first 5 minutes of the activity. Mean EE during ES was calculated over 4 blocks of 5 minutes each. EE was expressed as kJ/hr.

Mean EE without ES was calculated over the first 5 minutes of the activity , before the start of ES. Mean EE during ES was calculated over 4 blocks of 5 minutes each. This in order to give insight in the progression of muscle fatigue during the 20 minutes of ES.

To evaluate feasibility, the participants filled out a questionnaire on a 5-point Likert scale (1 totally disagree; 5 totally agree) directly after each activity, consisting of the statements: 1) the ES is uncomfortable, 2) it is possible to lie/sit/ propel during ES, 3) other ADL are feasible while using ES.

F. Statistical Analysis

A General Linear Model Repeated Measures ANOVA was used to evaluate if EE during ADL with ES was higher than without ES. A paired sample t-test was used to determine whether EE during each separate activity increased during ES. In addition, the EE during the 20 minutes of ES was split into 4 blocks of 5 minutes and analyzed with a Repeated Measures ANOVA. All statistical tests were performed with SPSS statistics 17.0 software.

III. RESULTS

EE was significantly higher during activities with ES compared to activities without ES ($p=0.025$). Analyzed separately, a significantly higher EE with ES compared to without ES was found for lying (416±134 vs. 342±81 kJ/hr, +21.6%, $p=0.009$) and sitting (375±70 vs. 318±38 kJ/hr, +18.1%, $p=0.005$). For wheelchair propulsion a trend was found for a higher EE with ES than without (673±187 vs. 617±177 kJ/hr, +9.0%, $p=0.095$). There was no interaction effect between the different activities and EE ($p=0.694$), suggesting that ES-induced activation resulted in a similar increase in EE for every activity. EE did not change during the 20 minutes of the activity with ES ($p=0.327$).

ES-induced activation was well tolerated by all participants and did not hinder the tasks performed. Generally, participants did not experience ES as uncomfortable (2.0±1), declared that ES did not hinder the activity (4.6±0.5), and stated it would be possible to use ES during other activities (4.0±1).

IV. DISCUSSION

This study showed that ES-induced muscle activation at comfortable levels is feasible, does not hinder ADL tasks and moderately increases energy expenditure. Extrapolating, the results suggest that ±3 hours of ES are required each day to compensate for the average excess energy intake of 182kJ in individuals with SCI and prevent a weight gain of 1.8 kg per year. Since the ES could theoretically be applied during the entire day and night, this makes the ES shorts a potentially valuable tool against obesity. It should be noted that our participants were not specifically trained for ES-exercise, so the results could even be more pronounced after a training period and concomitant increases in muscle mass and fatigue resistance. In addition, this method can lead to additional positive effects, such as improved circulation, improved pressure distribution, and reduced pressure sores risk [6-8].

Although other methods such as arm cranking can induce much higher levels of EE and therefore may seem to be more effective, not everyone is capable of executing or willing to perform these kinds of activity at an adequate intensity and for a sufficient volume. Whether this increase in EE actually results in weight loss or weight gain prevention has to be evaluated in randomized experimental controlled studies.

V. CONCLUSION

ES-induced paralyzed muscle activation markedly increases EE during daily activities in SCI and might therefore be a potential way to help counteracting the development of obesity.

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