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Abstracts of Poster Presentations

1 MONITORING PATIENTS WITH SCI DURING ACTIVITY USING A DATA LOGGER

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A Compumedics "siesta" data logger was used to set up and trial a study of a range of physiological and other changes following spinal cord injury (SCI). This was an extension of work performed in sleep laboratory testing in both able-bodied individuals and those with SCI at Austin RMC. During rehabilitation (3 to 30 weeks post-injury), there were changes expected with neurological and functional recovery. The data logger is small and lightweight, with 16-bit resolution, sampling rates (4–512 Hz per channel), 32 flexible channels, digital filtering during collection review, and communications, including direct digital readout for SAO_2, heart rate (HR), continuous positive airway pressure, body position, remote monitoring of all channels via radio local area network, and flash card or hard disk storage. Measurement systems included ECG (512 Hz), thoracic and abdominal respiration (16 Hz), pulse oximetry (8 Hz) to measure SaO_2 and heart rate, accelerometers (64 Hz) to pick up different types of movement such as shoulder movements pushing a chair, use of the arm ergometer, or smoking, as well as body surface and environmental temperature and to act as an event button. Six traumatically injured spinal patients each had five tests aiming to

- develop the current data logger system in a moving environment;
- minimize interference and optimize quality data retrieval;
- perform more effective, longer studies;
- measure/study physiological parameters of normal daily activities;
- study the effects of everyday stresses such as physiotherapy, eating, and environment on the physiology of an individual SCI patient over time;
- measure changes in physiology over a three-month study; and
- determine if there were common group changes.

Data analysis involved pattern recognition and simple analysis of electronic signals, including more focused signal analysis. Examples of activities demonstrating change include (1) distinct, recognizable patterns of activity looking at combinations of signals, e.g., pushing a wheelchair, smoking, or environment change; (2) HR during physiotherapy decreased then gradually recovered; (3) a rapid rise in HR ~10 min after lunch (10–20% above baseline); (4) reciprocal changes in blood pressure to pulse rate differed from controls; (5) less change with lower neurological level and greater time post-injury; (6) ECG signal analysis (RR variability) indicated vagal tone, and complex HR analysis (spectral) mirrored this; and (7) patterns appear consistent across a small group. Data logger measurements have revealed some changes in physiology, including "autonomic failure" unique to SCI patients during normal activity. The cooperative evolution of a wheelchair laboratory is envisaged and the problems with this and potential solutions are raised.

2 PHYSICAL STRAIN DURING WHEELCHAIR BASKETBALL COMPETITION: INDIVIDUAL HEART RATE EVALUATION CONCERNING TEAM SPORT VARIABLES

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In team sports, like wheelchair basketball (WB), fitness training methodology has to be defined from the evaluation of the individual physiological strain during competition and related to specific team sport variables. As adapted sport, players' functional classification has to be considered. The purpose of this study was to present and implement a protocol to measure the physiological strain in WB through heart rate (HR) monitoring during high-level competition, as well as the individual physiological answer-related game situation in WB (game action/reglementary pause), player's tactical situation, and functional classification. Two highly trained WB players (members of the WB Spanish National Team) were monitored with an HR monitor (HR recording every 5 s) during seven matches of high-level competition (national and international competition). Both players underwent a maximal graded exercise test on a wheelchair ergometer [1] to determine individual maximal aerobic parameters and anaerobic thresholds. Physical strain was evaluated from the formula presented by Janssen [2], calculating the personal HR related the individual HR reserve (%HRR). Video analysis was performed by a trained and independent observer to define players' tactical situation every 5 s. Tactical situation is defined by a categorical frame of observation based on rules and depends on the role of the player, strategy, and opponent behavior. Observational categories are exhaustive and mutually exclusive: (1) offense with the ball, (2) offense without the ball, (3) defense to the player without the ball, (4) defense to the player with the ball, (5) reglementary pause, (6) substitution, and (7) free-throw shooting. Nine and a half hours were evaluated for every player in seven matches. The average number of data registered by match and player was 953 (±147), full-match mean duration was 79 min, 25 s (±1 min, 45 s). General strain per match (without category 6) was 117.5 percent of %HRR for player 1 (spinal cord injured level D6, class I, forward) and 157.1 percent (±17.1) for player 2 (polyomielitis both legs, class III, playmaker). An independent t-test showed significant differences between action/pause situation for both players (player 1: 60.4% (±16.3) and 51.2% (±17.2) of HRR for action/pause situations, respectively; player 2: 81.0% (±11.3) and 70.2% (±14.6) of %HRR for action/pause situations, respectively). For strain-related tactical situations, there were significant differences (ANOVA, $p < 0.05$) between action categories (1 and 4) and pause (5 and 7) for both players. The more demanding situation was attacking with the ball (1). Man recovery is 10 percent of %HRR during pause categories (5 and 7), with respect to action categories (1 and 4). The intermittent nature of WB is doubtless. Regular WB practice supposes a physiological stress sufficient to obtain a cardiovascular improvement in persons with spinal cord injury. To study physical strain in team sports competition, and, still more in adapted sports such as WB, HR information has to be related, at least, with personal characteristics (age, weight, height, etc.), but overall with functional classification of the player.

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3 RECRUITMENT GROUP FOR ACTIVE REHABILITATION (RG)—ADAPTING THE CONCEPT TO NORWAY: IMPLEMENTING ADVANCED ACTIVITY TRAINING ACCORDING TO THE SWEDISH RG CONCEPT IN NORWAY

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Rekrutteringsgruppen (RG) Aktiv Rehabilitering—Recruitment Group for Active Rehabilitation—or RG Norway, is a nonprofit organization. RG works with the physical and mental training of physically disabled individuals, mainly those with spinal cord injury (SCI). Our goal is to help disabled people develop the strength and self-confidence to succeed in becoming independent. The aim of this ongoing project is to investigate the need to establish a Norwegian model of Recruitment Group for Active Rehabilitation outside institutions following primary rehabilitation for individuals with SCI in Norway. Sixteen subjects with SCI (<15 years, American Spinal Injury Association [ASIA] AE, injured no more than 5 years) participated in a one-week, 24 h program in June 2003. Out of 30 applicants, 16 were chosen to participate in the study. The instructors, 53 percent of whom had longstanding SCI (ASIA AE), acted as role models and coaches during the camp program. The instructors had their own life experience in a wheelchair and could show what was possible to achieve despite a physical handicap. Both participants and instructors completed questionnaires to evaluate goal achievement and accomplishment/feasibility of the program. Results and evaluation forms from the camp program in 2003 will be presented, along with plans of the camp planned in October 2004. The project demonstrated the same positive trend that has been reported from similar projects in Sweden and show that there may be a need for a Norwegian model of Recruitment Group for Active Rehabilitation outside institutions in Norway. Preliminary results tell us that active rehabilitation may contribute to increased independent living and to a better integration into the community. Experiences from Sweden indicate that the project can develop to become a well-established organization. Further investigations and prolongation of this project may contribute to support this concept.

4 VOCATIONAL REHABILITATION OF PEOPLE WITH SPINAL CORD INJURY: A LITERATURE SURVEY

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Being employed is known as an important indicator of quality of life for people with spinal cord injury (SCI). A combination of many factors seems to influence the employment of people with SCI. Until now, a systematic analysis of determinants of employment was lacking. Three models seem helpful in the analysis of vocational rehabilitation in people with SCI: the "model of work strain" [1], the process model of vocational rehabilitation [2], and the International Classification of Functioning, Disability and Health (The Netherlands WHO-FIC Collaborating Centre, 2002). The purpose of this study was to systematically investigate which factors may influence the employment of people with SCI. First, we searched the literature with the help of Picarta en PubMed on the internet. We checked the references of the literature we found for additional publications. Finally, we searched these secondary publications for special issues. The model of work strain was followed to structure our study [1]. This model attempts to reflect the processes raised by work in humans in terms of work capacity. We ultimately found few scientific studies, so we used the secondary literature as well. The first component of the model of work strain is concerned with the individual's ability to deal with the consequences of the SCI. In particular, physical capacity, functionality, secondary impairments, education, age and the coping style are indicators of a successful vocational rehabilitation. The second component deals with possible work stress factors and workers' latitude.

Access to the workplace, lost functionality and physical capacity, amount and contents of work, working velocity, relationship with colleagues, working hours and workers' latitude seem to be determinants of successful vocational rehabilitation. Several environmental adaptations and assistive technology may reduce these barriers. The last components of the model deal with the short- and long-term effects of work. Working can be physically and emotionally positive for the individual with SCI, especially if the worker can be provided optimal accommodations in the workplace. To systematically analyze the factors influencing the outcome of vocational rehabilitation of people with SCI, we combined the three models concerned with the vocational rehabilitation. This combination resulted in a new model that could be used to optimize the process of vocational rehabilitation. One important limitation of our analysis was the lack of scientific literature; as a result, our analysis could not be based solely on scientific information. More systematic studies (longitudinal and multicenter) must be performed to gain a more profound understanding of the determinants of successful vocational rehabilitation in SCI. These determining factors are in the personal context and in the context of the work and workplace. Therefore, in persons with SCI, we recommend systematic analysis of the physical, cognitive, and emotional capacity for each individual in the light of work stressors, personal latitude, and the short- and long-term consequences of the work stressors. The new model formulated in this study can be used as a guide.

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5 EPIDURAL METASTATIC SPINAL CORD COMPRESSION: FUNCTIONAL OUTCOME AND SURVIVAL AFTER INPATIENT REHABILITATION

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The purpose of this study was to obtain an overall appraisal of patients with epidural metastatic spinal cord compression (SCC) admitted to 9 Dutch spinal cord units (SCU) between January 1, 1990, and January 1, 2000; and to identify factors that predict survival >1 year after inpatient rehabilitation of patients with epidural metastatic SCC. In this retrospective descriptive study, clinical records were reviewed, and demographic, clinical, and functional data were collected according to a protocol. Date of admittance to the SCU, rehabilitation goals, date of discharge, and date of death was recorded. The Odds Ratio (OR) was calculated for all determinants on admittance to the SCU, in order to find indicators that predict survival >1 year after discharge from the SCU. An OR >2 was considered to be clinically significant. Survival >1 year after discharge from the SCU, feasibility of going home after clinical rehabilitation, and physical capacity were mentioned as the most important criteria for admittance of patients with epidural metastatic SCC for inpatient rehabilitation. A total of 131 patients with epidural metastatic SCC were admitted. Of these, 117 clinical records were retrieved, and 97 clinical records provided complete data. The average age on admittance was 58 years and 53 percent of the patients were male. Average Barthel score on admittance was 7.2/20 points. The average length of stay in the SCU was 104 days (3–336). Sixty-six percent of the patients were discharged to their home and the average Barthel score on discharge was 12.0 points. The average survival after discharge was 808 (0–3669) days. Seven patients died during their stay on the SCU. One year after discharge, 52 percent of

the patients were still alive, and these patients had made better functional progress. The Barthel score increased from 8.1/20 to 15.5 points (in comparison, in the group that survived less than 1 year, the Barthel score increased from 7.2/20 to 12.0 points). These patients also suffered fewer complications, had been admitted less often to a hospital during rehabilitation, had achieved more goals, and had been discharged home more often. A survival >1 year after discharge is related to American Spinal Injury Association (ASIA) D (OR 4.3), MRC 4 and 5 (OR 5.4), tumor in remission (OR 3.8), and independence or partial independence on the Barthel items dressing (OR 4.3) and making transfers (OR 5.0). This study shows that inpatient rehabilitation can be successful for a selected group of patients with epidural SCC.

6 THE USE OF ELECTRICAL STIMULATION FOR PREVENTION AND TREATMENT OF PRESSURE SORES

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Pressure sores are a common problem for individuals with spinal cord injury (SCI), resulting in great discomfort and significant medical-care costs. Those with SCI are at increased risk for pressure sores because of factors such as reduced mobility, reduced microcirculation, impaired sympathetic function, muscle atrophy, and impaired sensation. Although special cushioning systems can better disperse seating pressures and thus reduce the risk of pressure sores, not all sores can be prevented. It is theoretically possible that electrical stimulation (ES) and ES-induced exercise can assist in pressure sore risk reduction, since they have been shown to increase muscle mass, capillary density, and skin and muscle blood flow. The purpose of this study is to discuss how ES can contribute to pressure sore risk reduction and pressure sore incidence and to evaluate how ES can be helpful in pressure sore healing once preventative measures have failed. Several studies have shown that ES and ES-induced exercise can have positive effects on factors reducing the risk of pressure sore development: muscle atrophy can be (partially) reversed, skin and muscle blood flow can be augmented, and seating pressures can be reduced. When prevention has failed, wound treatment is necessary and ES might be a treatment option, since it may assist the human body's endogenous bioelectric system that enhances healing of bone fractures and soft-tissue wounds. Several studies describe the positive effects of ES on a cellular and organic level in wound healing. Also, ES increases blood flow and can reduce edema. ES is safe and relatively simple to apply. We have not encountered a study describing adverse or negative side effects of ES on the patient or the wound. Many animal studies show that ES can be effective in wound treatment, confirmed by several clinical studies on humans. It is plausible that regular ES-induced exercise can reduce the incidence of pressure sores, but the lack of controlled studies disallows a definitive statement. Physicians are often not familiar with ES as a treatment option in addition to conservative or operative measures in wound healing. ES is currently not often used for treatment in wound healing. In protocols for wound treatment, scientific medical advisory boards do not advise to do so, referring to a lack of evidence of efficacy. Methodologically good-quality studies for the effectiveness of ES in wound healing are indeed limited. But, when taken together, the collective efficacy studies and the collective "mechanism of action" studies provide a strong indication that ES has a direct positive effect on tissue and is effective for promoting the healing of pressure sores. Instead of focusing on the limited scientific data available and unanswered questions, we believe ES should be used more often in clinical practice for pressure sore prevention and wound treatment. More high quality studies can follow to ascertain cost-effectiveness.

7 HOW TO MEASURE SPINAL CORD INJURED PATIENTS' TRUNK BALANCE

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This study is part of a larger research program about the benefits of wheelchair dance, where it was necessary to appraise objectively the balance improvement these patients have reported. The aim of this study is to choose an efficient method to appraise trunk balance in patients with spinal cord injury (SCI) in the sitting position. Balance control is viewed as a fundamental ability, in as much as it constitutes a prerequisite for movement initiation. So, SCI, as well as other lesions to the sensory systems, the central nervous system, and the skeletal-muscle system, may hinder such ability, indicating the importance of postural balance measures in studies not only related to SCI, but also to general physiology, geriatrics, neurology, and traumatology. Biomechanics is the field that provides the necessary tools to evaluate various movement and balance-related parameters. After a theoretical study, we began preliminary tests in the Biomechanics Laboratory of the University of Brasilia using dynamometry, electromyography, and cinematography. Through an analysis of the theoretical framework, physiological basis, and historical evolution of techniques, this study reviews the main methods for measuring balance, in order to offer a broad range of possible topics for future research. We found that methods based on dynamometry, force-plate, and electromyography did not fit to our objectives. The force-plate is a good method to appraise static balance, but it does not fit to dynamic balance evaluation. Electromyography gives us important information about nervous system and muscle function, but does not show us the improvement of the trunk movement in the space. In this investigation, video recording was found to be an efficient mode for appraising dynamic trunk balance in SCI.

8 DEGENERATION OF LONG-TERM DENERVATED HUMAN SKELETAL MUSCLE IS REVERSIBLE

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Spinal cord injury (SCI) causes a rapid loss in both contractile force and muscle mass, which is especially severe when the injury involves lower motoneurons. Over the last 30 years there has been a good deal of interest in the use of functional electrical stimulation (FES) to restore movement of the limbs of patients paralyzed by upper-motoneuron lesion. An innovative rehabilitation procedure based on a modulated and prolonged stimulation of long-term denervated and degenerated muscles (DDM) has been developed with the aim of reversing muscle atrophy and degeneration in patients with lower-motoneuron lesions [1]. The purpose of the present work is to study the effects of our training FES protocol on the structure of long-term DDM fibers. Muscle biopsies were taken from the right and left vastus lateralis muscle. The samples obtained were first fixed and then embedded in an epoxy resin. Ultra-thin sections (approximately 40 nm) were cut in Leica Ultracut R and the specimens were then examined with a Philips 505 Morgagni Series 268D electron microscope, equipped with Megaview III digital camera. Our results shows that lack of innervation in muscle fibers results in the parallel degeneration of both contractile and excitation-contraction coupling (ECC) apparatuses. ECC is the mechanism that enables communication between T-tubules that carry motoneuron impulses and sarcoplasmic reticulum (SR), which contain the Ca^{2+} needed for

muscle activation. This mechanism occurs at specialized junctions called triads, or calcium release units. Myofibrils that in DDM are extremely disorganized and/or completely missing are reformed and realigned with one another following FES. In parallel, the triads—which in long-term DDM are rare, generally disorganized, misshapen, and incomplete—are relocated and reoriented correctly in correspondence to the sarcomere I-A junctions of the sarcomere in muscle treated with our FES protocol. The poor excitability of human long-term DDM fibers during the first stages of FES training could be explained in terms of spatial disorder of both the ECC and contractile apparatuses. The reorganization of the contractile and ECC apparatuses appears to occur in parallel, but it remains to be established which is the leading process. These structural studies are extremely encouraging, because they demonstrate that the protocol used during FES training is effective in reverting the atrophy and the degeneration that follows long-term denervation and in maintaining the trophic state of newly regenerated myofibers.

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9 TECHNICAL DESIGN OF A NOVEL ISOKINETIC FES EXERCISE BICYCLE FOR SPINAL CORD INJURED INDIVIDUALS

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An isokinetic functional electrical stimulation leg cycle ergometer (iFES-LCE) was developed for individuals with spinal cord injury (SCI) for use at home or in a rehabilitation center. The iFES-LCE was designed to allow cycle training over a broad range of pedaling cadences (560 rev•min^{-1}) that would promote both lower-limb muscular strength and cardiorespiratory fitness after SCI. This paper describes the technical details and development of the iFES-LCE. The core components of the iFES-LCE consisted of a commercially available motorized cycle ergometer, a laptop PC running purpose-built software, and a custom-designed 6-channel transcutaneous neuromuscular stimulator (DS2000). The design of the iFES-LCE was fundamentally different from prior FES-LCE ergometers, and relied on the motorized ergometer for velocity and force-feedback control. The constant-velocity motor permitted the ergometer to operate safely over a wide range of cadences (560 rev•min^{-1}), and allowed the calculation of accurate power outputs by compensating for the passive load of the legs. Data from the motorized ergometer were transmitted to software on a laptop PC that regulated the neuromuscular stimulation delivered by the DS2000. Twenty-five design criteria were identified to be achieved within the scope of the technical design of the iFES-LCE. Calibration of the iFES-LCE system revealed a linear relationship between torque applied to the axle of the motorized ergometer and the braking motor current generated to maintain velocity. Performance data derived from iFES-LCE motor torque agreed closely with similar data collected with strain-gauge instrumented pedals (cross-correlations = 0.93–0.98). The iFES-LCE was shown to work well across a range of pedaling cadences. Twenty three of 25 design criteria for the iFES-LCE were achieved in the current design. The iFES-LCE is ideally suited to research or home use because of the user-friendly interface, and changes can be easily made to the software running on the laptop PC or the microcontroller in the DS2000. The new iFES-LCE system may offer improved training potential by allowing cycling over a broad range of pedaling cadences, especially slow cadence, where augmented muscle strength may be a desired outcome. This device also improves on the accuracy of other ergometers by adjusting for the passive load of the legs in the calculation of torque and power output. It is hoped that the dissemination of the iFES-LCE's technical details and design will assist the proliferation of FES cycling in rehabilitation centers and the home environment for individuals with spinal cord injury.

10 THE DEVELOPMENT OF A HYBRID FES BIKE

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After the introduction of the stationary FES (functional electrical stimulation) bike 20 years ago, there have been several attempts to build an outdoor FES bike for people with a spinal cord injury (SCI). One of the problems faced by these groups was the lack of produced power output and stamina by the stimulated legs. Another problem is the poor maneuverability of a tricycle compared to a wheelchair. The goal was to design a FES bike that is suited for independent use, both indoors and outdoors. The mechanical, electronic, and software development of the bike involved an extensive network of companies and institutions. The BerkelBike (the name of this FES bike) is a mixture of a "clamp-on hand bike" and a recumbent bicycle. The front part of the BerkelBike can be attached to most available wheelchairs, increasing acceptability by users and freedom of movement. In some cases, a pillow behind the back is necessary to give the user a more recumbent position to enable the cycling movements of the legs. When arm cranking is started, the legs will make passive cycle movements until FES is initiated. Around the crank axle a goniometer is placed that measures the position of the pedals in 56 steps. On the basis of this information, the quadriceps, hamstrings, and gluteus muscles are stimulated with surface electrodes. The 12 stimulation electrodes are placed inside a cycling short and can be worn underneath trousers. During cycling, the rider can control the intensity of the stimulation by a ± switch. To convert the outdoor bike to a stationary bike, the front wheel is placed in a holder with an electrical roller brake against the tire. Nine BerkelBikes have been provided to SCI patients (T3–T11) for home use. They are asked to use the bike for at least 30 min, three times per week, for 12 weeks. Most subjects can use the latest model of the BerkelBike independently. They can reach about the same speed as with normal clamp-on hand bikes. They can uncouple the front part, which allows them to use their wheelchair. With FES, the muscle power can progress relatively quickly, which could potentially lead to overloading of joints. To avoid this problem, the use of the BerkelBike could be limited in the first year. The BerkelBike represents the first time an outdoor FES bike is suited to be independently used by a large group of individuals with SCI.

11 PHYSIOLOGICAL RESPONSES DURING ARM CRANK AND HYBRID PEAK EXERCISE: EVALUATION OF A HYBRID TRAINING PERIOD IN INDIVIDUALS WITH PARAPLEGIA

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The purpose of this study was to assess the physiological responses during a graded peak arm crank exercise test (GAT) and a graded peak hybrid exercise test (GHT), before and after a hybrid training period in individuals with paraplegia. Ten subjects with paraplegia (T3–T11) performed a GHT and a standardized GAT prior to (T0) and after 4 weeks of hybrid training (T1). The subjects trained 8 to 12 times (for 30 min at 70% peak heart rate) in 4 weeks on the BerkelBike, a new hybrid training device (FES-stimulated leg cycling combined with arm-crank exercise) that can be used indoors as well as outdoors by individuals with paraplegia. The GHT was done on the BerkelBike. The GAT was performed on a Lode arm ergometer. During the exercise tests the following variables were continuously measured: peak oxygen uptake (VO_2),

peak carbon dioxide output (VCO_2), expired ventilation (VE), peak heart rate (HR), and peak power output (PO). An analysis of variance (ANOVA) for repeated measures (2 × 2 design) was used to assess the training effect (T0–T1), the differences in the physiological responses between the GHT and the GAT, and the interaction between GHT and GAT and training (T0 and T1). At both T0 and T1, GHT elicited a significantly higher peak VO_2 (27% and 32% higher, $p < 0.001$), VCO_2 (25% and 24% higher, $p = 0.010$), and a significantly lower HR (9% and 14%, $p = 0.008$) compared to the graded arm-cranking exercise test. There was a tendency toward a higher VE during the GHT (18% and 15% higher); however, this trend was not significant ($p = 0.072$). Unexpectedly, there were no significant differences in RER and PO. According to both peak exercise tests, the training period significantly improved VO_2 ($p = 0.008$), VCO_2 ($p = 0.004$), VE ($p = 0.018$), and PO ($p = 0.003$). On the GHT and the GAT, respectively, the following respective improvements were seen: VO_2: 9 percent and 6 percent; VCO_2: 9 percent and 10 percent; VE: 7 percent and 9 percent, and PO: 12 percent and 7 percent. No differences due to training were found for RER and HR. Obviously, there was no interaction between maximal test and training. Because of a lower HR (increased stroke volume because of an increased venous return) and a higher VO_2 and VCO_2, the GHT peak test provides a reduced cardiac stress and greater metabolic stress than arm-crank peak testing alone. These test-specific effects indicate that hybrid training must be evaluated with a GHT test. Whether hybrid exercise also will provide greater gains in cardiovascular fitness, and may be a better training method than upper body exercise alone, must be studied in future research. Physical fitness improved after 4 weeks of hybrid training. Since the measured training effect was, percentage-wise, equal in both testing modes, the training effect was comparable in both FES-stimulated leg exercise and arm work. The GAT, as well as the GHT, can be used to evaluate the effects of a 4-week hybrid training period. The hybrid training leads to significant improvements in both arm and FES-stimulated leg exercise.

12 EFFECTS OF ELECTRICAL STIMULATION-INDUCED LEG CYCLING ON MUSCLE FUNCTION DISORDERS OF INDIVIDUALS WITH SPINAL CORD INJURY

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Muscle function disorders, such as spasticity, spasms, and muscle stiffness, are a common impediment to individuals with a spinal cord injury (SCI) during daily life activities such as sitting, keeping balance, transferring from bed to chairs and vice versa, and sleeping. Until now, there have been many therapeutic interventions to reduce various components of the spasticity syndrome. However, the effectiveness of these interventions has not been proven yet and is not always clear. One method, used since the 1950s, makes use of electrical stimulation (ES). A few studies have shown that ES to the muscle with the disorder can result in spasticity-reducing effects. An exercise method that incorporates computer-controlled ES to induce leg cycling may also have effects on muscle function disorders. Although many users have indeed reported to experience a temporary reduction in spasticity, little experimental information is yet available to evaluate the effects of cycle ergometry training with ES on muscle function disorders and functional performance in individuals with SCI and to compare these with the effects after passive leg cycling without ES. Ten individuals with SCI (male or female) in clinical or post-clinical treatment at the Rehabilitation Center Amsterdam will participate in this study. On two occasions, each subject will perform a 30 min cycling test on a computer-controlled leg cycle ergometer. During one test, the subject will actively cycle (with ES) and during the other test, the subject will passively cycle (an assistant will move the pedals). During several tests (immediately

before, after, and 1, 4, and 24 h after), the degree of muscle function disorders will be measured with the use of an adapted isokinetic dynamometer. Passive movements of the lower leg will be performed at various velocities ranging from 15 to 180 degrees per second. The recorded resistance will provide information on spasticity and muscle stiffness. The degree of fatigue will be quantified with the use of ES of the m. quadriceps. In addition, each subject will perform two transfers that will be recorded on digital video and evaluated based on the Barthel index and time needed to perform the activity by a blinded physical therapist. The occurrence of "spontaneous" spasms will be quantified with the use of surface EMG. This study is currently under way. Preliminary data indicate that muscle function disorders are significantly reduced after ES-induced leg cycling.

13 TREADMILL TRAINING WITH BODYWEIGHT SUPPORT: POSSIBILITIES IN FUNCTIONAL GAIT TRAINING WITH SPINAL CORD INJURED PEOPLE

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Within physical therapy, the use of bodyweight-supported treadmill training (BWSTT) can be an important supplement of the exercise possibilities in the process of the relearning of walking. In the last several years, patients have had BWSTT in the rehabilitation center at Sint Maartenskliniek, four of whom had a severe incomplete cervical spinal cord injury. For these four patients, there was no other way to start with walking exercises. The motor capacity of the legs was too small to bear the bodyweight, and the motor function of the arms was too limited to compensate for the lack of leg function. In the beginning of the BWSTT, the help of two experienced physical therapists was needed. The bodyweight support was set at 40 percent (±10), and the treadmill was set at a speed of 0.4 km/h (±0.1). The time that the patient was walking on the treadmill in one therapy session was 2 × 5 min. The level of assistance was adjusted so that a maximum contribution of the walking activity during stance phase was delivered by the patient. In the beginning, the swing phase was usually assisted by the physical therapists. An important aspect of the BWSTT was the verbal feedback to patients about their performance. In this way, the patients and physical therapists were searching for an optimal coordinated walking pattern so the patient could re-experience gait. During the course of the training sessions, the level of weight support was decreased and the walking speed increased in a way that the walking pattern stayed optimal. The level of assistance was also decreased. As soon as the patient could bear 75 percent of his weight, the training was continued over-ground in an exercise room where the patients started training with two therapists and an adapted rollator. The training was continued until the patient could walk in the home situation with the help of one person and a rollator. BWSTT is an important tool in rehabilitation to make a start in gait training for people with severe incomplete spinal cord injury. However, experience in BWSTT and insight from the physical therapists with respect to the relearning of gait, in combination with adequate training equipment, are required to achieve a solid approach and a maximum effect.

14 LOCOMOTOR ACTIVITY FOR AN IMPROVEMENT IN THE LIFE QUALITY OF SPINAL CORD INJURED PATIENT

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Traumatic spinal cord injury (SCI) involves a loss of body functions caused by injury to the spinal cord. Recovery of the lost body functions can be achieved by regeneration of

severed axon tracts or by a rerouting of signals via remaining intact tracts. However, functional recovery depends not only on the regeneration of injured fiber tracts. Although hind-limb use and locomotor function to some extent depend on the appropriate supraspinal control, it is known that the central pattern generator (CPG) plays a pivotal role in the generation of hind-limb movements, including stepping. The CPG is a network of intraspinal neurons that are able to generate stepping movements without supraspinal input. Training of the CPG may improve the functional outcome after SCI. It has already been shown in clinical trials that humans with longstanding, functionally incomplete and complete SCI can regain some locomotor ability with specific training paradigms. The improvements in locomotor function are thought to depend on local plastic changes in the CPG after the training protocols. Therefore, one of the aims of Spinal Cord Europe Education & Research (SCEER) is to open health centers where locomotor training paradigms for spinal cord injured people are present. Besides a possible recovery of functionality, an increased locomotor activity will render an enormous attribution to the quality of spinal cord injured people's lives. First, these people will be able to reduce their daily time spent in their wheelchairs. Second, their blood circulation will be improved, which may lead to a decrease in the presence of bed sores. Third, there may be a reduction of muscle atrophy and a better constitution of the bone tissue. Last, but certainly not least, the mental condition of spinal cord injured people will dramatically improve.

15 BODYWEIGHT SUPPORTED TREADMILL TRAINING IN CHRONIC INCOMPLETE SPINAL CORD INJURY: A PILOT STUDY INCLUDING FUNCTIONAL HEALTH STATUS

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This study investigated the effects of treadmill training (TT) on functional health status (FHS) in subjects with a chronic incomplete spinal cord injury (ISCI). The study was a controlled single-case design: A1 (baseline: 6 weeks), B (intervention: 12 weeks of TT, maximally 5 times a week for 30 min a day), A2 (washout: 6 weeks), follow-up measurement: 6 months. The study was performed in the Rehabilitation Department of the University Medical Centre Utrecht, The Netherlands. Subjects were three male subjects with a stable (>48 months post-injury) ISCI, American Spinal Injury Association (ASIA) class C (n = 2) and D (n = 1), assessed for performance-based walking, subject's perception concerning quality of life (QoL), and activities of daily living (ADL). The results of the three subjects were variable. Changes in QoL, during and after TT, were relatively small and diverse. After 6 months' follow-up, QoL was unchanged in subjects 1 and 2, but improved in subject 3. In subject 2, performance of ADL was significantly improved, consistent with his perception of improvement (p < 0.05), and this improvement was sustained throughout the follow-up period. Walking ability improved in subject 3 (p < 0.05), but other performance of activities remained stable. Performance of ADL decreased slightly in subject 1, but walking speed and Get Up and Go performance improved (p < 0.05). This study demonstrates effects of TT on walking capability, QoL and perceived problematic ADL, during and 6 months after TT.

16 EIGHT-CHANNEL STIMULATION SYSTEM FOR MOBILIZATION OF PARAPLEGIC PATIENTS

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Surface stimulation of lower extremities in paraplegic patients with intact lower motoneuron is a functional electrical stimulation (FES) application to provide walker- or crutch-supported standing up from the wheelchair and walking (stepping) for short distances. A PC-supported, eight-channel stimulation system was developed. Two four-channel stimulation modules (one for each leg), one power and communication device, and a standard palmtop computer for parameter management are integrated in a belt and can be worn around the hip. Stimulation is triggered by pressing a switch on the crutch- or walker-mounted remote control. Via a wireless LAN, a connection to a standard PC can be established. The PC software used in the clinic or rehabilitation center allows the individual optimization of stimulation parameters in a comfortable way. After the clinical trial session, the data set can be downloaded to the palmtop computer for home use. For safety reasons, the patient has little ability to change the stimulation parameters, mainly the stimulation intensity. Six experienced FES users volunteered to test the system. It was well accepted and proved to be reliable and easy to use. As a first step for commercialization, the system is currently undergoing a clinical trial according to EN ISO 14155.

17 PERFORMANCE DIAGNOSTIC IN HANDBIKING DURING A CITY MARATHON

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The prerequisite for an adequate performance control is the analysis of the profile of demand. For this reason, in the present study, exercise-induced, metabolic, pulmonary, cardiovascular, and energetic reactions of a paraplegic athlete were investigated at the occasion of the 5th Cologne Ford Marathon. A 27-year-old male athlete took part in this study after he had been informed about details and risks of the investigation and after he had signed his written consent for participation. The athlete had a complete traumatic spinal cord injury at the level of T4. In the competition the athlete used his own race handbike, whose crank system had been exchanged for a power measurement system with registering option. This technical device made it possible to continuously register speed, load, crank frequency, physical energy consumption, and heart frequency during the whole race distance. For measuring ventilatory gas parameters during exercise, a portable spirometric system was used. The athlete managed to finish the marathon race after 1:48:54 h, despite the fact that he wore the spirometry mask and had to make several stops for blood sampling. The mean oxygen uptake (O_2) during the marathon was 1580 ml/min with a maximum value of 2535 ml/min. The mean heart frequency was 137 bpm with a maximum of 157 bpm. During the race the mean energy consumption was 463 kcal/h with a maximum of 758 kcal/h. Thus, the energy consumption during the total marathon period (1:48:54 h) amounted to 838 kcal/h. On the average the respiratory exchange ratio (CO_2/O_2) was 0.88, which indicates that the portion of fatty acid oxidation is approximately 40 percent of the total energy production (proteins are not considered). The mean respiratory frequency of the athlete was 53.2/min with a maximum of 79.7/min, and the mean ventilatory minute volume was 62.0 l/min with a maximum of

97.3 l/min. Prior to the race, the blood lactate value was 2.9 mmol/l; after 10 km, 4.4 mol/l; after 20 km, 2.9 mmol/l; and after 30 km, 2.9 mmol/l. In conclusion, competition-oriented handbikers should concentrate on exercise units of long duration at low intensities—as do marathon runners or cyclists—in order to improve their aerobic performance capacity. The aim is to achieve a very high portion of fatty acid oxidation within the process of energy delivery. However, it has to be pointed out that athletes with paraplegia develop relatively high metabolic intensities in competition and that the variability of their physiological parameters is considerably high. Therefore, general recommendations aiming at the control of their training intensities can only be given if the respective individual prerequisites are taken into account and if they undergo regular scientific investigations to verify their efficiency.

18 EFFECT OF HAND CYCLE MODE ON POWER OUTPUT AND PHYSICAL STRAIN AT SUBMAXIMAL AND PEAK PERFORMANCE

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Hand cycling has evolved into a widely accepted form of outdoor manual wheelchair ambulation for sports, recreation, and activities of daily living (ADL). It is commonly propelled through synchronous arm exercise. This study evaluated performance during synchronous (SYNC) and asynchronous hand cycling (ASYNC) at submaximal and maximal levels of exercise. Gross mechanical efficiency (ME), oxygen uptake, and external power output (PO) were the prime outcome measures studied. Nine male unimpaired and untrained subjects (AB) (age 20.1 ± 2.1 years) performed two (sub)maximal discontinuous hand cycle exercise tests in both the SYNC and ASYNC modes. Tests were conducted in a standardized commercial attach-unit tricycle (counterbalanced order). Treadmill speed and slope were changed in a fixed sequence of 3 min exercise steps. Gears were adjusted such that cycle frequency was kept at 65 rev/min. During the exercise test, external power output (PO) was continuously monitored with an SRM [1]. A separate conventional wheelchair drag test was performed to estimate mean PO. Heart rate (HR) (beats/min) and oxygen uptake (VO_2) (ml/kg/min, SMTP) were continuously monitored. An analysis of variance for repeated measures was used to evaluate differences between the two arm modes ($p < 0.05$). Subjects, on average, reached peak levels of performance (RER: 1.05 ± 0.07 vs 1.10 ± 0.1 for SYNC and ASYNC). As was to be expected, peak PO and VO_2 were significantly higher for SYNC (81.6 ± 11.8 vs. 68.5 ± 10.6 W; 26.4 ± 4.5 vs. 21.2 ± 3.0 ml/kg/min). Peak HR also appeared significantly higher during SYNC. At submaximal exercise levels, ME was significantly higher for SYNC (12.1 ± 0.9 vs. 9.7 ± 1.4% at 41 W). Much to our surprise, no significant differences were found among the values for PO (at equal velocity and slope), as derived from the SRM (SYNC and ASYNC), and from the drag test. As has been previously described, ASYNC is less efficient compared to SYNC. This has been shown for AB, as well as subjects with a spinal cord injury (SCI). Similarly, peak performance values have been shown to be significantly higher in both AB and SCI for SYNC [2]. It was, however, expected that we would find a higher external PO for ASYNC at equal slope and speed. The SRM values did not differ significantly, however (conversely, SYNC PO tended to somewhat higher mean values). Contrary to expectations, the drag test did not underestimate PO. The lower peak performance and ME in ASYNC may be explained by the increased stabilizing muscle effort in the upper extremities (and trunk) in order to combine power production with stable steering. This muscle action can be described as a “freezing out” movement in the frontal plane in the shoulder, elbow, and wrist, as well as around the longitudinal axis of the trunk This probably will be differently controlled in SCI. Compensatory mechanisms for

stability will probably take place, possibly involving a different use of the backrest. SYNC is more efficient than ASYNC and leads to higher peak performance. SRM readings did not differ between SYNC and ASYNC, and the drag test serves a close estimation of PO. Mechanisms of stabilizing muscle control in SYNC and ASYNC must be studied in AB and SCI.

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19 THE EFFECTS OF CADENCE UPON EXCESS POST-EXERCISE OXYGEN CONSUMPTION DURING UPPER BODY EXERCISE

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It is well known that both exercise intensity and duration are key factors in determining the magnitude of excess post-exercise oxygen consumption (EPOC) [1]. Manipulating cadence during upper body exercise has been shown to increase metabolic rate (oxygen consumption) and, consequently, exercise intensity for a given power output [2]. Such a manipulation could therefore induce changes in EPOC after a given bout of exercise. Therefore the aim of this study was to examine the effects of cadence upon EPOC after arm crank exercise of an intensity and duration commonly undertaken during physical conditioning. Eight healthy able-bodied subjects (mean ± SD age 22.1 ± 4.7 years, height 1.81 ±0.09 m, weight 80.9 ± 12.2 kg) volunteered to take part in the study, which received University Ethics Committee approval. All subjects were regularly engaged in physical training, but not specifically for the upper body. After familiarization and a test for peak oxygen uptake (VO_{2peak}), subjects undertook three exercise trials in random order, at 60 percent O_{2peak} for 10 min at a cadence of 50, 70, and 90 rev•min^{-1}. Expired gas was continually sampled for 10 min at rest, during exercise and 30 min recovery via an online gas analysis system (Cortex, Metamax). Heart rate was continually monitored (Polar, Favour). Blood pressure was measured via auscultation and earlobe arterialized capillary samples was assayed for blood lactate (BLa) at rest, 5, and 10 min of exercise and 5, 10, 15, and 30 min of recovery. Ratings of perceived exertion for overall ($RPE_{overall}$) and local effort (RPE_{local}) were recorded (Borg Scale) and the difference between them calculated (RPE_{diff}) as an indicator of local fatigue. Total oxygen consumption during recovery (TOC) and the time taken for metabolic rate to return to midway between exercise and resting oxygen consumption (EPOC1/2time) were calculated. Data were analyzed by a two-way analysis of variance with repeated measures on both factors (cadence × time). Although heart rate, peak ventilatory flow, breathing frequency, minute ventilation, oxygen consumption, and systolic blood pressure tended to be greatest during 90 rev•min^{-1}, no significant differences were observed between cadences. However, main effects were observed ($p < 0.05$) for BLa, being greater throughout exercise and recovery, and RPE_{diff}, being lower during 90 rev•min^{-1} (7 ± 1) when compared to 50 (5 ± 1) and 70 (2 ± 1) rev•min^{-1}. No differences were observed between trials for TOC (12.5 ± 1.9, 11.5 ± 2.7, 12.1 ± 3.2 l) or EPOC1/2time (69.6 ± 12.3, 60.1 ± 10.9, 60.5 ± 16.9 s) or $RPE_{overall}$. These results suggest that cadence has no effect on EPOC parameters during arm-crank ergometry of short duration and moderate intensity, but does affect the contribution of anaerobic energy sources and effort perception during exercise. These latter factors may have important implications for exercising training and rehabilitation.

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20 EFFECT OF HAND CYCLE TRAINING ON PHYSICAL CAPACITY AND WHEELCHAIR SKILLS IN PERSONS WITH A TETRAPLEGIA

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Synchronous hand cycling (HC) is a common form of wheeled ambulation for daily use, sports, and recreation in persons with a spinal cord injury in The Netherlands. HC is more efficient and less straining than handrim wheelchair propulsion. Therefore HC seems to be a useful alternative for improving physical capacity (PC) in persons with a spinal cord injury, even in those with tetraplegia (TP). To determine the effects of an 8-week HC training program on physical capacity and wheelchair skills in persons with TP, eight moderately trained subjects with TP (>2 years post-injury) were tested before and after the training period. The training protocol consisted of 30 min interval training sessions, 3 times a week, with an intensity of 70 to 90 percent of peak heart rate. Outcome measures of PC are endurance capacity (maximal oxygen uptake [VO_{2peak}], submaximal oxygen uptake [VO_{2sub}] and maximal power output [PO_{max}]), measured during a standardized discontinuous maximal hand cycle test on a motor-driven treadmill, muscle strength (handheld dynamometry), and pulmonary function. Wheelchair skills were evaluated by measuring performance time and heart rate in a standardized wheelchair skill test. Results showed significant improvements for VO_{2peak} (16%, pre: 1.53 and post: 1.74 l/min) and for PO_{max} (21%, pre: 62.0 and post: 74.7W). VO_{2sub} decreased significantly with 17 percent. No improvements were found for arm strength, pulmonary function and wheelchair skills. Results indicate that HC training improves EC in moderately trained persons with TP, but has no effect on muscle strength, pulmonary function and wheelchair skill performance. Interval training appears a suitable training method for TP.

21 THE VAN LIESHOUT TEST FOR HAND FUNCTION

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From 1995 until 2002, the Hoensbroeck Rehabilitation Center in The Netherlands, in cooperation with iRv Institute for Rehabilitation Research, developed an assessment protocol in order to be able to describe the arm and hand function of patients with tetraplegia in a qualitative reproducible way. The absence of a suitable instrument triggered this initiative, and a new test was constructed: The Van Lieshout Test (VLT). The VLT is the first qualitative test instrument developed specially for all tetraplegic patients. It assesses the wide range of tetraplegic manifestations: higher and lower cervical injured people, complete and incomplete, for conservatively as well as surgically treated patients. The instrument is not only representative in a scientific way but also gives direct feedback on therapeutic exercise and training. The VLT test assesses the qualitative development of the functions as well as the potentials of the upper extremity. It is based on standards of excellence to the highest feasible goals of each neurological level. Positioning, stabilizing, development of the function hand, and hand skills are the main issues of the test. The VLT is tested valid and reliable. It will be internationally published in 2004. The test supports decision-making by surgeons, rehabilitation specialists and patients about therapy goal setting and treatment.

22 VALIDITY OF THE VAN LIESHOUT TEST FOR HAND FUNCTION OF PEOPLE WITH TETRAPLEGIA

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The Van Lieshout Test (VLT) is an assessment and measurement instrument for hand function of people with tetraplegia. Compared to the Grasp-Release Test, the VLT takes less time and covers a wider range of activities. To assess the construct validity of the VLT, a cross-sectional study was performed in people with tetraplegia in The Netherlands. The GRT was used as criterion measure. Further, the International Classification, the Quadriplegia Index of Function (QIF), and the Self-Care scale of the FIM were administered. Strong correlations between the VLT and GRT were expected, as were moderate correlations between the VLT and the other measures. Fifty-five patients participated in the study. Eighty-three percent were men, and mean time after injury was 11.0 years (SD ±8.5). Most injuries were motor complete (74.5% American Spinal Injury Association [ASIA] A or B). Spearman correlations between the VLT and the GRT were very high: 0.87 for the left hand and 0.90 for the right hand, demonstrating good criterion validity. Correlations between the VLT and the other measures were between 0.65 and 0.85. The VLT is a valid measure of hand function in tetraplegia. Its inter-rater reliability is subject of ongoing research.

23 PHYSICAL STRAIN, WORK CAPACITY AND RESTORATION OF MOBILITY IN THE REHABILITATION OF INDIVIDUALS WITH A SPINAL CORD INJURY: A MULTICENTER STUDY

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Restoration of mobility during rehabilitation of persons with a spinal cord injury (SCI) is often directed to a generally wheelchair-bound daily life. SCI frequently implies a shift from leg to arm work. This impacts cardiovascular, respiratory, neuromuscular and skeletal adaptations, in terms of physical strain, work capacity and functionality. Changes in (neuro)physiological and biomechanical functioning take place due to SCI on the one hand and active rehabilitation on the other. Further, apart from the primary and secondary consequences of the spinal

injury, wheelchair use itself sets major constraints to social integration. Little is known of the process of mobility restoration in SCI rehabilitation, let alone of detailed adaptations in function and functionality or the associations among these, and outcome at the level of activities and participation. An outline is given of a national multicenter research program into the understanding of physical strain, work capacity and mechanisms of restoration of mobility during and after the inpatient rehabilitation of individuals with SCI. Currently the program consists of 11 research projects. These projects are conducted in a network of 8 collaborating rehabilitation centers and 4 research groups. The program has the following general objectives: (1) the development of a fundamental and clinical knowledge base of adaptations in organ systems and of mechanisms of restoration of mobility from (neuro)physiological, biomechanical and technical perspectives; (2) the development of a knowledge base of effects of rehabilitation and exercise on overall work capacity and functional outcome; (3) the analysis of associations between impairment, activity and participation in the light of restoration of mobility; and (4) the understanding of the material and process requirements for optimal restoration of mobility during and after rehabilitation of SCI. The core project is a prospective cohort study (currently n = 203) in which function, functionality, as well as activities and participation are systematically measured and monitored at four subsequent occasions: at the start of the active rehabilitation, 3 months later, at the conclusion of inpatient rehabilitation, and 1 year after rehabilitation. Eight local (paramedical) research assistants and physiatrists were responsible for successfully conducting the measurements and the integration of results into the common database. This epidemiological core study is complemented with both experimental and intervention studies in subgroups of patients, focusing on questions of mobility restoration at the level of function (cardiovascular and respiratory adaptation, upper extremity [UE] motor control in tetraplegia, FES in marginal walkers, UE mechanical loading, UE treatment policy in tetraplegia), functionality (hand cycling, daily physical activity) and participation (transmural nursing, allochtonous patients, patient involvement in SCI research). The majority of studies is funded by Netherlands Organization for Health Research and Development. A network of researchers, physiatrists, therapists, PhD students and research assistants actively collaborate since the start of the program in 1999. The network meets in mini symposia each half year in one of the rehabilitation centers. The program and network are gradually implemented into the existing professional organization, Dutch-Flemish Society of Paraplegia. This will further support the implementation of research results, which are presented in different other contributions to the conference. Patient-related research, implementation and treatment in spinal cord injury rehabilitation will benefit from multicenter research collaboration at the level of (para)medical and research professions.

24 VALIDITY OF THE DETECTION OF WHEELCHAIR PROPULSION OF MEASUREMENTS WITH AN ACTIVITY MONITOR IN PATIENTS WITH SPINAL CORD INJURY

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Everyday physical activity is an important aspect and outcome measure of the rehabilitation process of patients with spinal cord injury (SCI). The aim of this study was to determine the validity of the detection of wheelchair propulsion (handrim wheelchair propulsion and handbiking) of measurements with an accelerometry-based activity monitor (AM) in patients with SCI. Ten patients with SCI (aged 19–63; 5 patients with poor tricep strength and 5 patients with good tricep strength) participated. Patients performed a series of representative daily life activities (wheelchair propulsion and non-wheelchair propulsion activities), according to a standard protocol, in a semi-natural setting. Continuous registrations of accelerometer signals were made and the AM output, after automatic analysis, was compared with visual

analysis of simultaneously made video recordings (reference method). Validity scores (agreement, sensitivity, specificity) between the output of the AM and the video analysis were calculated. Mean (and range) overall agreement, sensitivity and specificity for the detection of wheelchair propulsion were 92 percent (87–96), 87 percent (76–99), and 92 percent (85–98), respectively. Sensitivity was smaller in patients with poor tricep strength compared to patients with good tricep strength: 81 percent (76–89) and 95 percent (89–99), respectively ($p < 0.01$). The AM is a valid instrument to detect wheelchair propulsion (handrim wheelchair propulsion and handbiking) in patients with SCI, both with good and poor tricep strength.

25 GROSS MECHANICAL EFFICIENCY OF HANDRIM WHEELCHAIR PROPULSION DURING REHABILITATION OF PERSONS WITH A SPINAL CORD INJURY

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During rehabilitation of wheelchair-dependent individuals with a spinal cord injury (SCI), task proficiency is expected to improve as a consequence of learning and training. During submaximal wheelchair propulsion, gross mechanical efficiency (ME) is viewed as an adequate indicator of overall task proficiency. Currently, no data exist in this respect. The purpose of this study was to describe and analyze changes in ME during SCI rehabilitation. In the context of a Dutch multicenter prospective cohort study, 23 subjects with SCI (3 subjects with tetraplegia, 5 females) performed three subsequent submaximal wheelchair exercise tests on a motor-driven treadmill: at the start of active rehabilitation (t1), 3 months later (t2), and at the end of clinical rehabilitation (t3). In each test, ME was evaluated for the final minute of each of two 3 min stages of submaximal wheelchair exercise in a standardized handrim wheelchair on a motor-driven treadmill. Changes over time were evaluated with an ANOVA for repeated measures—main factors (levels): time ([t1,2,3], (3)); exercise stage (2); level of significance: $p < 0.05$. Mean power output was 9.2 ± 4.3 W and 13.5 ± 5.2 W for the subsequent two stages at t1, and showed a small but significant increase over time (10.0 ± 4.2 W and 14.8 ± 4.9 W for the respective two stages at t3). Oxygen uptake showed a slight nonsignificant downward trend over time. Mean ME significantly increased for the first stage from 5 ± 2 percent at t1 to 5.6 ± 2.1 percent at t3, and from 7.1 ± 2.5 at t1 to 7.8 ± 2.6 percent at t3 for the second exercise stage ($p < 0.01$). Mean heart rate and ventilation significantly dropped over time at both levels of power output ($p < 0.01$). Results show a steady increase in wheeling proficiency over time, indicating effects of learning and training during the course of rehabilitation. At a later stage of this multicenter study the role of lesion level, completeness of the lesion, age, and gender on ME will be evaluated.

26 LIPID PROFILES DURING REHABILITATION OF PEOPLE WITH A SPINAL CORD INJURY

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Unfavorable lipid profiles have been reported in persons with chronic spinal cord injury (SCI) and are characterized by depressed levels of high density lipoprotein cholesterol (HDLC) and elevated levels of low density

cholesterol (LDLC). This suggests that persons with SCI may be at increased risk for coronary heart diseases, which may be caused by physical inactivity or other injury-related factors. The purpose of this study was to determine the course of lipid profiles during rehabilitation of persons with SCI, and to investigate the relationship with lesion level and completeness of the lesion. Within the framework of a Dutch multicenter prospective cohort study, lipid profiles (total cholesterol (TC), HDLC and LDLC) of 188 subjects with SCI (77 with tetraplegia) were measured at the start of active rehabilitation (t1), 3 months later (t2), and at the end of clinical rehabilitation (t3). Percentages of subjects at risk (TC > 6.2 mmol/l, HDLC < 0.9 mmol/l, LDL ≥ 4.1 mmol/l) were calculated for t1, t2, and t3. Changes in lipid profiles were investigated with the use of generalized estimating equations (GEE) with time of measurement, lesion level, motor completeness of the lesion, and the interactions of lesion level and completeness with time, as independent variables. Age, sex, and body mass index (bodyweight/length^2 were added to the equation as control variables. The GEE method enables the use of all repeated measures for predicting the dependent variable, regardless of the number of observations. Time between t1 and t3 was 206 ± 124 days. Percentages HDLC < 0.9 mmol/l were 33, 24, and 20 percent, TC > 6.2 mmol/l were 10, 7 and 9%, LDL; 4.1 mmol/l were 10, 6 and 7 percent, at t1, t2 and t3, respectively. Overall, HDLC improved significantly from 1.03 mmol/l at t1 to 1.13 and 1.19 mmol/l at t2 and t3, respectively, and TC and LDLC showed no significant changes during rehabilitation. Values were not different between persons with tetraplegia and paraplegia. HDLC showed significantly higher values for persons with incomplete lesion compared to those with complete lesions, while no differences were found for TC and LDLC. Both lesion level and completeness of the lesion did not affect changes in the lipid profile. There was a significant interaction between lesion level and time for TC between t1 and t2, indicating that persons with tetraplegia showed larger increments in TC between t1 and t2 than persons with paraplegia. No significant interactions were found for lesion level and time for HDLC and LDLC or for completeness and time. Depressed levels of HDLC, but normal TC and LDLC were found at the start of active rehabilitation. HDLC increased during rehabilitation, but still 20 percent were at increased risk for coronary heart diseases at discharge (t3). Lesion characteristics were of minor influence on the course of lipid profiles.

27 RESPIRATORY FUNCTION IN PERSONS WITH SPINAL CORD INJURY DURING THE FIRST MONTHS OF REHABILITATION

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Persons with spinal cord injury (SCI) may suffer from impaired respiratory function, resulting in a limitation of the ability to breathe deeply and cough effectively. This increases the risk for developing respiratory complications, which remains a major cause of morbidity and mortality following SCI in the acute post-injury period and in the chronic phase. The purpose of this study was to quantify the vital lung capacity and expiratory flow in persons with SCI during the first months of rehabilitation. As part of a Dutch multicenter prospective cohort study, spirometry was performed by persons with a recent SCI, at the start of active rehabilitation (T1: as soon as the subject was able to sit 3 to 4 hours in succession) and 3 months later (T2). The mean forced vital capacity expressed in percentage of normal-predicted value (FVC%) and mean peak expiratory flow expressed in percentage of normal-predicted value (PEF%) were determined for the following subgroups: high motor-complete tetraplegia (HT) (American Spinal Injury Association [ASIA] AB, C5 and above, not requiring mechanical ventilation), low motor-complete tetraplegia (LT)(ASIA

AB, C6–C8), high motor-complete paraplegia (HP) (ASIA AB, T1–T6), low motor-complete paraplegia (LP) (ASIA AB, T7–L5), incomplete tetraplegia (IT) (ASIA CD), and incomplete paraplegia (IP) (ASIA CD). One-way analysis of variance (ANOVA) was used to calculate the mean and standard deviation (SD) for each subgroup; Tukey post-hoc tests were used to identify significant differences between groups. Paired t-tests were applied to determine significant changes in FVC% and PEF% over time within each group. Spirometry at T1 was performed by 162 persons with SCI (mean (±SD) age: 36.7 (±14.1) years). Mean (±SD) FVC% and PEF% for the different subgroups were: HT group: 43 (±15) percent and 38 (±12) percent, LT group: 64 (±15) percent and 46 (±11) percent, HP group: 70 (±20) percent and 53 (±18) percent, LP group: 77 (±21) percent and 59 (±18) percent, IT group 80 (±26) percent and 62 (±21) percent, IP group: 93 (±32) percent and 74 (±23) percent. Post-hoc analysis showed a significant difference ($p < 0.05$) for FVC% between the HT group and all other groups, and between the IP group and the HQ, LQ, HP group; for PEF% between the HT group and all but the LQ group; and between the IP group and all but the IQ group. The FVC% and PEF% (n = 133 persons) significantly improved ($p < 0.008$) over time for the total group (mean (±SD): 7.9 (±12.6)% and 5.6 (±14.5)%, respectively), and for several subgroups (FVC%: HQ, LQ, HP, LP group; PEF%: HQ and LP group). As could be expected the vital lung capacity and expiratory flow were lowest in persons with the largest loss of function. It is important to realize that there were persons with severe limited respiratory function in all subgroups. Therefore we feel that it is necessary to assess respiratory function in all persons with SCI in the early stage of rehabilitation, to help identify those at risk for respiratory complications. Improvement in FVC% and PEF% during the first 3 months of active rehabilitation indicates a positive effect of rehabilitation treatment on respiratory function. Vital lung capacity and expiratory flow were lowest for persons with high motor-complete tetraplegia and highest for motor-incomplete paraplegia and improved during the first 3 months of rehabilitation.

28 EFFECT OF BACKREST CUSHION AND POSITIONING ON THE BIOMECHANICS OF MANUAL WHEELCHAIR PROPULSION IN CHILDREN WITH CEREBRAL PALSY

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One of the major objectives targeted by the rehabilitation team is the increase of the wheeled mobility in children with cerebral palsy (CP). Manual propulsion in wheelchair necessitates the coordination of inter-segmental limbs, such as trunk and upper limb. This coordination is realized by the management of postural stability and by the production of minimal force acting against the mechanical friction at the pushrim level. Although there is abundant research addressing the biomechanics of wheelchair propulsion in adults with spinal cord injury, little to no information is available concerning the forces applied to the pushrim during manual wheelchair propulsion for children with cerebral palsy. The purpose of this study is to analyze the effect of different backrests and positioning on the biomechanics of wheelchair propulsion for children with CP. Seven subjects with moderate diplegia were asked to propel manually in a simulator wheelchair with randomly selected three different backrests, the adjustable tension backrest (ATB), the Jay2 rigid backrest as well as the flexible contour backrest (FCB). Kinematics of the upper limb was assessed by the VICON motion analysis system at 120 Hz, whereas the force and moment were measured by the SmartWheel^{TM} at 240 Hz. The mechanical

usage index (MUI) was calculated as the ratio between the actual total force acting at the handrim and the maximal voluntary force. The fraction of the effective force (MEF) was calculated. Finally, the projection of the shoulder marker onto the line of action of the total force was estimated and represents the lever arm (LA). There was no significant difference between the three backrests for the MUI parameter. However the latter was higher in mean value (49%) and maximal value (71%) in comparison with other populations of wheelchair users. There was a significant difference ($p < 0.01$) on the MEF parameter between the three backrest cushions: 71 percent, 68 percent, and 63 percent for the ATB, the Jay2, and the FCB, respectively. At the same time, the LA parameter indicates significantly ($p < 0.001$) a higher value for the Jay2 (284 mm), followed by the ATB (251 mm), and the FCB (242 mm). It has been suggested recently that if the line of action of the resultant force at the handrim intersects the shoulder joint during the push phase, then the moment at the shoulder will be minimized. Our data indicate that the FCB backrest minimizes the LA parameter during the propulsion cycle. The MUI data value found in this study is considered very high, since we know that, on average, force grip strength in children with CP is 25 to 55 percent lower than the corresponding normal population. The results highlight the fact that the positioning, as well as the backrest, had a significant effect on the biomechanics of manual wheelchair propulsion in children with cerebral palsy.

29 EFFECTS OF TASK CONSTRAINTS ON WHEELCHAIR PROPULSION TECHNIQUE AND GROSS MECHANICAL EFFICIENCY AFTER 3 WEEKS OF PRACTICE

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The main purpose of the study was to investigate the influence of task constraints, i.e., learning environment, on gross mechanical efficiency (ME) and propulsion technique during the learning process of handrim wheelchair propulsion. The following hypothesis was tested: inexperienced wheelchair users will achieve a larger improvement in ME and propulsion technique when they practice in an environment that is closer to real-world wheeling conditions. Thirty able-bodied subjects were selected and randomly divided over three experimental groups; one group practiced on a treadmill (TREAD; $n = 10$), one group on a testing track on the floor (FLOOR; $n = 10$) and one group practiced on an ergometer (ERGO; $n = 10$). All groups practiced for three weeks, three times a week, at an average speed of 1.11 m/s^{-1}. Every trial comprised two 4 min exercise blocks, preceded by 2 min of rest for all groups. The blocks performed on the treadmill and the ergometer comprised two different levels of external power output (block 1: 0.15 W/kg^{-1} and block 2: 0.25 W/kg^{-1}). FLOOR practiced without extra resistance. Measurements of propulsion technique (timing and work per cycle [WpC]) and physiology were done during trials 1 and 9. To detect significant differences between groups, an ANOVA for repeated measurements was applied with block (1 and 2) and trial (1 and 9) as within-subject factors, and group (TREAD, FLOOR, and ERGO) as a between-subject factor ($p < 0.05$). In contrast to expectations,

learning environment had no significant effect on ME (Time × Group effect: $p = 0.38$). Also no significant increase in ME after the 3weeks practice period—regardless of practice environment—was seen (Time effect: $p = 0.49$; ERGO: block 1: 5.6 ± 0.7% to 5.9 ± 0.5%, and block 2: 7.5 ± 1.0% to 8.1 ± 0.6%; TREAD: block 1: 4.2 ± 1.0% to 4.3 ± 1.2%, and block 2: 4.2 ± 1.0% to 4.3 ± 1.2%, and block 2: 6.2 ± 0.9% to 6.9 ± 1.0%; FLOOR: block 1: 4.4 ± 1.3% to 4.4 ± 0.8% and block 2: 4.7 ± 0.9% to 4.2 ± 0.7%). No significant Time × Group interaction effect was found for the cycle frequency, push time, and cycle time. However, all groups showed a significant decrease in cycle frequency (ERGO: ±20, TREAD and FLOOR: ±10 pushes/min^{-1}) and subsequently a significant increase in push time and cycle time. A significant Time × Group interaction effect ($p = 0.03$) was found for the WpC. ERGO (block 1: 13.9 ± 2.1 J to 21.7 ± 7.3 J and block 2: 22.7 ± 3.9 to 32.7 ± 11.0) showed a significantly larger increase in WpC compared to TREAD (block 1: 14.5 ± 5.4 J to 14.1 ± 4.0J and block 2: 26.3 ± 7.8 J to 29.6 ± 8.4 J) and FLOOR (block 1: 12.8 ± 3.4 J to 14.9 ± 4.6 J and block 2: 13.7 ± 4.5 J to 14.3 ± 4.1 J). Although all groups changed in a positive direction, no significant differences between the different learning conditions could be established under the current experimental conditions. The wheeling conditions may have been at an external power output too low to generate noticeable differences among the practice environments. The lack of results of some variables over time might be the consequence of the constant power output in both practice blocks of FLOOR.

30 SEAT HEIGHT IN HANDRIM WHEELCHAIR PROPULSION DURING SCI REHABILITATION

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Seat height in manual wheelchair ambulation has been shown to affect submaximal physical strain and propulsion technique in (un)impaired individuals. In terms of gross mechanical efficiency an optimum seat height has been described in relation to elbow angle, as defined in a standardized sitting posture, relative to elbow angle. The purpose of this study was to evaluate the effect of seat height manipulation relative to elbow angle on gross mechanical efficiency (ME) and propulsion technique in subjects with a spinal cord lesion (SCI) during their initial rehabilitation. Eight male and four female SCI (age: 19–77 yr, lesion level: C5/C6–L2; 8 incomplete) conducted a series of eight submaximal handrim wheelchair exercise tests at different seat heights. Subjects performed the steady state handrim wheelchair exercise tests (4 min) in a counterbalanced order on a stationary computer controlled wheelchair ergometer at a constant, but individualized power output (5.4–13.9 W; $v = 0.42$–0.83 m/s). Seat height varied for each test from 70 to 140 degrees of elbow angle (full elbow extension = 180 degrees). Seat height was adjusted according to a fixed procedure (subject sitting in the wheelchair ergometer with the acromion over the wheel axis; with the hands at top-dead-center of the handrim; seat height was adjusted relative to elbow angle). Last minute physiological and technique data (among others: fraction effective force [FEF], total force [Ftot], mediolateral [Fy] and vertical force [Fz] components and push time [PT]) were collected and results were evaluated with the use of a

repeated measures ANOVA ($p < 0.05$). All physiological data—including ME—showed significant differences ($p < 0.05$) with seat height. Visual inspection of the physiological data showed a tendency for seat height to optimize at 100–130 degrees of elbow angle with a clear detrimental physical strain at the 80 and 90 degrees conditions. FEF decreased (71–58%) and Ftot, Fy, and Fz on average increased significantly with increasing seat height. PT remained constant. Mean submaximal work capacity is very low during SCI rehabilitation. Cardiovascular strain appeared a confounding factor in the current experimental setup. Also, due to "ergometer fitting problems," only a few subjects could fulfill the 70-degree condition. Still, mean physiological data indicated a tendency to optimize with seat height. This trend does not seem to relate to the trends seen in technique data, which seem to be regulated by different task or geometry-related boundary conditions. Data were evaluated on group level only, irrespective of lesion level. A preliminary regression analysis showed an impact of lesion level on the physiological data. Future studies must verify to what extent lesion level has an impact on the seat height results. It was concluded that the optimum level of seat height—relative to elbow angle—for efficient submaximal wheelchair propulsion in SCI during rehabilitation tends toward a 100- to 130-degree condition. Individual seat height evaluation during SCI rehabilitation may lead to a more optimal fitting of the handrim wheelchair for submaximal performance.

31 EFFECT OF WHEELCHAIR STROKE PATTERN ON MECHANICAL EFFICIENCY

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Different types of movements during handrim wheelchair propulsion were described in the literature, which can be primarily characterized by the trajectory of the hand during the recovery phase. Based on literature findings, it was assumed that the semicircular pattern, i.e., a more or less "circular or elliptic" recovery motion of the hand below the handrim, was the most efficient stroke pattern. In contrast, a movement with the hand returning along a path similar to that in the push phase, but in the opposite direction, a so-called "pumping" movement was assumed to be the least efficient stroke pattern. To investigate the effect of different wheelchair stroke patterns on mechanical efficiency, propulsion technique and the mechanical load on the upper extremity joints. Inexperienced able-bodied subjects were randomly divided over two velocity groups (1.11 m/s [$n = 14$] and 1.39 m/s [$n = 11$]). External load was set at 0.23 N/kg. Subjects performed four 4 min exercise blocks on a stationary, computer-controlled wheelchair ergometer in a counterbalanced order. They propelled the wheelchair with a freely chosen pattern and with the pumping, semicircular or single looping over propulsion pattern (in which the hands rise above the handrim during the recovery phase). Gross mechanical efficiency and propulsion technique variables were measured. For four subjects, input data (position and force) were collected for the Delft Shoulder and Elbow Model to calculate the mechanical load on the shoulder. A significant difference was found for mechanical efficiency with pumping

showing the highest values (7.1% ± 1.0 and 7.6% ± 0.9 for both velocities) and semicircular the lowest (6.7% ± 1.2 and 7.0% ± 0.8), regardless of velocity. Timing variables and negative power deflections before and after the push phase showed significant differences between the stroke patterns. The freely chosen and pumping stroke patterns showed a significantly higher cycle frequency (varying between 61 and 70 cycles per minute) compared to the other two stroke patterns (varying between 53 and 56 cycles per minute). The semicircular pattern showed the lowest power loss before the push phase, while the single looping over propulsion pattern showed the lowest power loss after the push phase. Stroke patterns showed no significant differences concerning peak joint moments and glenohumeral contact forces. In contrast to expectations, pumping is the energetically most efficient stroke pattern in contrast to the semicircular pattern in this able-bodied novice subject group. Propulsion technique and modeling results could not explain the differences in efficiency. The muscle contraction velocity might be more optimal in pumping compared to the semicircular pattern.

32 CORRECTIVE FORCES REQUIRED TO BALANCE IN A WHEELCHAIR WHEELIE

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To balance on the rear wheels, the body/wheelchair center of mass (COM) must lie within the base of support, in this case, the contact area between the wheels and the ground. The strategies that individuals with spinal cord injury use to keep the COM in alignment within the base of support are poorly understood. The purpose of this study was to determine directional changes in applied force, and magnitude of force required to balance in a wheelie. Two men with C7 tetraplegia and two men and one woman with paraplegia provided informed consent to participate in the study. Subjects had to be able to "pop a wheelie" and balance on the rear wheels for 1 min without assistance to be included in the study. All but one subject (female) mentioned that they perform wheelies on a regular basis. SmartWheels™ (Three Rivers Holdings, Mesa, ARIZONA), force, and torque sensing pushrims were installed on the subject's own wheelchair. Subjects were asked to practice performing a wheelie first, to become acclimated to the experimental setup. Pushrim forces sampled at 240 Hz and were recorded for 20 s, during which time the subject popped a wheelie and balanced in a wheelie position until given a verbal cue after 18 s to land the front casters. The resultant force from the SmartWheel™ was computed and plots of the force were visually inspected to discern the initial lift off of the casters from the wheelie balance phase. The middle 5 s of the balance phase were isolated and used for analysis. The number of corrections was determined by counting the number of local maximum (peak) force values. Each maximum was indicative of a change in force direction. Correction frequency was defined as the number of corrections per second. The average difference in force magnitude (corrective force) between each local maximum value was also determined. Subjects applied an average of 2.6 N of corrective force (range: 0.2 to 10.6 N) to balance in a wheelie. The number of corrections ranged from 45 to 114, and corrective frequencies ranged from 9 to 22.8 directional changes per second. Although frequent adjustments in the direction of force application were found, the amount of force exerted was generally very small (1.0 N), with the exception of the female user, who did not regularly perform wheelies. She was found to apply the highest corrective forces at the lowest frequency. Thus, it may be that wheelchair users who are less proficient at wheelies are less familiar with their "balance point" and allow the COM to deviate further from the base of support before making a correction which in turn needs to be large to compensate for the large COM displacement. Persons who perform

wheelies regularly and know their balance point make frequent but subtle adjustments with their hands to compensate for smaller detectable deviations in COM displacement. Proficient wheelie performers may be more apt to make force corrections of higher frequency and lower magnitude rather than lower frequency and higher magnitude.

33 IMPINGEMENT IN RELATION TO WHEELCHAIR-RELATED TASKS

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Following spinal cord injury (SCI), the upper extremity (UE) must be conditioned to withstand the cumulative forces of weight bearing. Tasks such as propulsion, weight transfer, and postural stability are shifted from the legs to the UE [1]. Since epidemiological studies have shown a high prevalence of shoulder complaints and shoulder pain in paraplegic and quadriplegic people, the conclusion appears to be warranted that the shoulder is not able to withstand the load that comes with these tasks. It is commonly accepted that shoulder pain is often associated with the subacromial impingement syndrome. Although it is not clear what causes impingement, it is possible that the decrease of the subacromial space while performing weight bearing activities plays an important role. To determine the influence of task properties a weight relief raise, on the occurrence of a decrease of the subacromial space with regard to shoulder impingement in people with SCI. Five paraplegic (T3–T9), four quadriplegic (C5–C7), and six able-bodied men participated in this study. All subjects underwent static strength tests of the abductors, adductors, and internal and external rotators before they had to perform three subsequent weight-relief raises. During the experiment Optotrak^{TM} (Northern Digital, Waterloo, Canada) was used to analyze the movements and kinetic data was registered with a force transducer (Advanced Mechanical Technology, Inc. MC3A61000) connected to the handrim. For the kinematic data, two parameters were determined: (1) the distance between the lateral epicondyle (EL) and the acromion (AC) and (2) the perpendicular distance between AC and a line from EL through an estimated center of the humerus. For both distances values during weight lifting were compared with values determined in the anatomical position. For the kinetic data the peak total force, measured on the handrim, expressed as %bodyweight (BW) and the direction of this force were determined. For the electromyographic data, the mean EMG as a percentage of the maximum voluntary contraction was determined for each muscle. Variables were evaluated with the use of a two-way factorial ANOVA, with 1 between-subject factor, the 3 subject groups, and 1 within-subjects factor, the 3 trials ($p < 0.05$). Peak total forces during the weight-relief raise were 37.75 (±2.87), 35.79 (±3.42), and 34.90 (±2.38) percent of BW, respectively for the paraplegic, quadriplegic, and able-bodied men. No significant differences were found among the subsequent trials ($p = 0.395$) or between the three groups ($p = 0.281$). The alterations of the distance between EL and AC were respectively 0.03 (±0.50), 0.06 (±0.16) and 0.08 (±0.34) cm, but there was a high variability found within the groups. No significant difference was found among the subsequent trials ($p = 0.168$) or between the three groups ($p = 0.836$). The main effect of the alteration of the subacromial space is negative, the distance decreased with 0.03 cm (±0.35). No significant differences were found between the three groups. Subacromial impingement could be developed due to the decrease in subacromial space, although there is no direct relationship with spinal cord injury. Other factors could be muscle imbalance, muscle weakness and overuse of the shoulder. The inter-individual variability found can be compared to the variability found in the study of Graichen et al. [2]. In healthy subjects also, a range from 6 to 14 mm in the neutral position has been reported.

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34 MANUAL WHEELCHAIR PROPULSION BY ELDERLY PEOPLE: A BIOMECHANICAL STUDY ALLOWING TO DESCRIBE A NOVEL FLEXIBLE CONNECTION BETWEEN HANDRIMS AND WHEELS

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The common manual wheelchair (MWC) uses a rigid connection between handrims and wheels. The utilization of such a rigid coupling might endanger the upper limb joints [1] and a more flexible coupling might be warranted. The presented research focuses on the design and validation of a new concept of flexibility between handrims and MWC wheels. Both handrims were connected to the wheels axle by the means of flexible leafs made of spring steel. Such a setup conveys a lower stiffness between handrims and wheels. Carbon fiber strips could be screwed onto the leafs, reinforcing the stiffness. Therefore, the modified MWC had three adjustments: rigid connection (RC), half (HF) and full flexibility (FF). To study the use of the modified MWC, the equipment was a computer-controlled wheelchair ergometer recording the angular speed of the wheels, and both wheels were mounted with a torquemeter, measuring the tangential forces on the handrims through a full set of strain gauges. The subjects were equipped with a heart frequency meter [2]. Ten subjects were selected with the following criteria: age above 60, no heart problems, and recent use of a MWC. Each test comprised 16 trials, in which the setup of the MWC was modified: RC, HF, and FF. When the heart rate was stabilized, the patient started to push the MWC at a stable and self-selected velocity. All trials, 45 s in duration, were separated by a rest interval. Each patient performed two tests at a time interval of one week. The studied variable (electronically linked) were velocity, A/P torque, and heart rate. A simple questionnaire was added, requesting the subjects' comments. When the FF configuration was used, there were too many oscillations of the handrims between the propulsive phases. This phenomenon appeared to be intolerable. Therefore, FF configuration was disused. The HF configuration led to a gentler increase of the propulsive torque relative to the RC condition. At equal velocity, the maximum torques were lowest with HF configuration, but the pushing phases lasted longer from HF to RC. Therefore, it appeared that the subjects lost some efficiency, but increased their comfort (as indicated by their responses to the questionnaire), in terms of shocks and vibrations. A flexible connection between the wheels and the handrims of MWC seems a totally novel concept. No literature on this idea could be found. Old and weak elderly females especially appreciated the novel MWC. The best adjustment of the flexibility was half flexibility. This adjustment was the best compromise between the efficiency of the propulsion (half stiffness) and comfort (half flexibility). On the other hand, males (especially the youngest) usually stated their preference as the rigid connection. However, it is important to notice that the main feature described above is the concept of flexibility to improve the propulsion of the MWC. Flexible and soft bumpers between the handrims and the wheels could be the definitive solution.

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35 EFFICIENCY OF SYNCHRONOUS AND ASYNCHRONOUS WHEELCHAIR PROPULSION AT TWO SELECTED PROPULSION SPEEDS

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Previous literature concerning the mechanical efficiency (ME) of wheelchair propulsion has shown a relationship between ME and push frequency [1,2]. Most literature has focused on the use of a synchronous (SYN) propulsion technique with limited investigation of asynchronous (ASY) propulsion techniques. With the exception of a study in handcycling [3] and a study with wheelchair propulsion [4], studies with the use of the ASY technique have employed arm cranking as the mode of exercise [5,6]. The purpose of this study was to examine the effect of push strategy-frequency (SF) combinations on ME at two selected propulsion speeds and two push frequencies during handrim wheelchair exercise on a roller ergometer. Twelve male able-bodied volunteers participated in this study. Participants attended the laboratory on two separate occasions, firstly undertaking a VO_2 peak test. The second visit involved the completion of six 4 minute submaximal exercise conditions consisting of three SF combinations (SYN40; ASY at 40 and 80 pushes/min, respectively) at two selected velocities (1.2 and 1.7 m/s). All tests were performed in a randomized order on a wheelchair ergometer (Bromking Turbo Trainer, UK) in a basketball wheelchair (RGK Interceptor). Physiological measures included oxygen uptake (VO_2), heart rate (HR), blood lactate concentration (BLa), and gross mechanical efficiency (GME). A two-way analysis of variance (ANOVA) with repeated measures was used, with strategy and velocity as independent variables to assess differences in physiological responses between conditions. Statistical significance was set at an alpha of $p < 0.05$. The mean VO_2 peak value was 2.49 ± 0.32 L/min, which ranged from 1.87 to 2.83 L/min. The average work intensity at 1.2 m/s represented 36 percent of VO_2 peak (SD ± 5.91%) and at 1.7 m/s, 57 percent of VO_2 peak (SD ± 6.77%). Analysis of ME revealed that participants were more efficient at 1.2 m/s than at 1.7 m/s. There were no significant differences between SF combinations at 1.2 m/s for any of the physiological variables measured (VO_2, HR, BLa and ME). However, at 1.7 m/s, mean power output of 42 W (SD ± 7 W) significant differences between SF combinations were evident for VO_2, HR and ME: $p < 0.05$. The SYN40 combination had a lower VO_2 than ASY40 (1.33 L/min and 1.51 L/min, respectively; $p < 0.05$), and a lower HR than ASY40 (109 vs. 117 bpm; $p < 0.05$). At 1.7 m/s ME for SYN40 (9.1%) was significantly different to ASY40 (8.1%): $p < 0.05$. In the SF combinations as the frequency was increased from 40 to 80 pushes/min, there was no significant effect on VO_2, HR, BLa and ME. At 1.2 m/s, the SF combination adopted by the participants had no resulting effect upon any of the physiological variables. In comparison, when velocity increased to 1.7 m/s, the SYN40 strategy was a more efficient method of wheelchair propulsion on a single roller ergometer than ASY40. The data seem to suggest that a SYN strategy is a more efficient method for wheelchair propulsion than ASY in able-bodied participants at the higher propulsive speed used in this study.

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36 PEAK PHYSIOLOGICAL RESPONSES TO ASYNCHRONOUS AND SYNCHRONOUS WHEELCHAIR EXERCISE

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Peak physiological responses during arm-crank exercise have been a topic of interest [1,2]. However, it is unclear how these findings may relate to wheelchair propulsion, which is a more complex, and less efficient mode of upper-body locomotion [3]. To examine the peak physiological responses during asynchronous (ASY) wheelchair propulsion exercise and compare these responses to synchronous (SYN) wheelchair propulsion exercise. Nine male able-bodied participants volunteered to participate in this study. Subjects attended the laboratory on two separate occasions. On each visit, subjects undertook a different wheelchair propulsion strategy (SYN vs. ASY) to determine VO_2 peak. All tests were performed in a basketball wheelchair (RGK Interceptor) on a wheelchair ergometer (WERG; Bromking Turbo Trainer, UK). Heart rate (HR) was monitored continuously and expired air samples were collected and analyzed with the use of the Douglas bag technique over the last two consecutive stages of the test. Differentiated ratings of perceived exertion (RPE) (overall, local, and central) and blood lactate concentration (BLa) were recorded on completion of the test. Push frequency was obtained from video footage during each stage of the test. A paired Student's t-test was applied to assess the significance of the differences in the peak physiological responses between SYN and ASY conditions. Statistical significance was set a priori at an alpha of 0.05. All subjects satisfied the criteria for a valid VO_2 peak, which was derived from the maximal RER and peak HR values. Individual peak values ranged from 2.16 to 3.85 L/min^{-1}. The mean VO_2 peak value attained during the SYN condition was slightly higher than that attained during the ASY condition (2.80 ± 0.54 L/min^{-1} vs. 2.62 ± 0.35 L/min^{-1}, respectively). It was found that those subjects who achieved the highest VO_2 peak and power output (PO) during the SYN condition generally achieved the higher values during the ASY condition (R = 0.79, $p < 0.01$ and R = 0.89, $p < 0.01$, respectively). There were no significant differences between SYN and ASY conditions for any of the physiological variables measured: VO_2 peak, PO, R, VE, HR, and BLa. Times to exhaustion (TE) were both 11.7 min, with slightly higher variability during the SYN condition as 2/9 subjects were able to reach a higher PO (42 ± 8 W vs. 41 ± 5 W for SYN and ASY, respectively). TE was limited by local fatigue as opposed to central RPE, which in fact was found to be significantly greater during the SYN condition (19.4 vs. 18.0; $p < 0.01$). Despite the fact that push frequency differed between conditions there was no difference in peak BLa (6.95 ± 1.18 mmol•L^{-1} vs. 7.00 ± 1.36 mmol•L^{-1}, SYN vs. ASY respectively). Both push strategies seem equally appropriate in determining VO_2 peak in able-bodied subjects. The recent adoption of ASY push strategies during sports performance would suggest that specific laboratory based protocols should allow athletes to self-select their push strategy. The merits of not constraining an athlete to the use a predetermined push strategy during aerobic fitness testing would improve the ecological validity and practicality of test data.

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37 THE INFLUENCE OF SEAT MODIFICATIONS ON THE MANUAL WHEELCHAIR PROPULSION: KINEMATIC ANALYSIS USING A POSTURAL ERGONOMETER

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Many studies show that the use of the wheelchair is really a displacement aid; some relate to the wheelchair instrumentation [1,2] or its adjustments [3,4]. Our work focuses on the influence of seat arrangement on the propulsion technique. For this, we developed a postural ergonometer based on a wheelchair. The seat of the ergonometer consists of a base and a backrest, adjustable in length, height, slope, and position. The wheels are slowed down by a variable magnetical resistance, ELITE. To analyze the propulsion technique, we used a 3D kinematic model, which included the upper limbs and the back. This model consists of marker coordinates recorded by VICON during the last 30 s of each run. Nine paraplegic and tetraplegic subjects took part in this study. We studied 18 conditions—3 conditions of base slope compared to the horizontal plane: parallel to the plane (NS), 30° to the plane (TS), and 15° to the plane (IS); 3 seat anterior-posterior positions relative to the rear wheel axis [3]: rear position (RP), neutral position (NP), front position (FP); and 2 resistance conditions: minimal (R_{min}) and maximal resistance (R_{max}). We analyzed two parameters: the joint amplitudes and the angular variations. The results used for the analyses are from five successive cycles for every condition. Analysis of the angular amplitudes of the back segments shows an influence of the seat position on spine mobility. By comparing RP with NP, we observed a reduction of spine mobility. This reduction is mostly located on the level of the lumbar segments, which is necessary for trunk stabilization. For condition FP, the angular amplitudes analysis of upper limbs showed a reduction in the elbow and shoulder flex-extension compared with NP and RP. The comparison of RP with NP showed a reduction in the wrist abd-adduction, the shoulder rotation and clavicle abd-adduction. In addition, abduction angles of the wrist at the beginning of the propulsive phase, for IS (18°) and NS (22°), conditions are higher than TS (11°), increasing the risk of wrist injury. For this tetraplegic subject, FP is not recommended because the back and the upper-limb mobility decreased comparatively with NP and RP. These results are confirmed by the smaller percentage value of the propulsive phase in the cycle (36%) compared to the 47 percent for NP and 46 percent for RP. We think that the rear position with a base angle of 30° is appropriate for this subject. Analysis of the influence of seat modifications on the kinematics shows the importance of the wheelchair selection at the time of its purchase, but also its arrangement. It is necessary to consider the use of wheelchair, the capacity to perform transfers, and also scab formation.

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38 THE WHEELCHAIR-HANDLING SKILLS OF CAREGIVERS AND THE EFFECT OF TRAINING

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This study was conducted to test the hypotheses that the wheelchair-handling skills of untrained caregivers are suboptimal and that the Wheelchair Skills Training Program (WSTP) is effective in improving these skills. We studied 10 caregiver/wheelchair-user pairs, the wheelchair users being inpatients at the Nova Scotia Rehabilitation Centre, carrying out pre/post-training within-participant comparisons. Caregiver participants underwent the WSTP (Version 2.4), adapted for caregivers. Training was individualized on the basis of an integrated testing-and-training protocol that took place on a single occasion (~50 min in total). The main outcome measures were the total percentage scores on the Wheelchair Skills Test (WST) (Version 2.4) and success rates for each of 50 individual skills. There were no adverse incidents. The mean (±SD) total percentage WST score, pretraining, was 75.8 (±12.8) percent. Posttraining, it rose by 24.8 percent (relative to the pretraining level) to 94.6 (±6.6) percent (p = 0.0039). The success rates of a number of individual skills improved by at least 20 percent (from least to greatest): the threshold (improvement of 20%), turns in place (20%), low curb descent (20%), gravel (30%), high curb (30–36%), arm rest (40–50%), folding/opening (40%) and assisted wheelie (60–70%) skills. The wheelchair-handling skills of untrained caregivers are suboptimal and the WSTP is a safe, practical and effective method of improving them. Such training could play an important role in the rehabilitation process.

39 A SELF-CONTAINED WIRELESS WHEELCHAIR ERGOMETER DESIGNED FOR BIOMECHANICAL MEASURES IN REAL-LIFE CONDITIONS

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Since the beginning of scientific research on wheelchair locomotion, various ergometers have been developed to investigate biomechanical constraints and physiological responses of wheelchair dependants in order to improve rehabilitation methods or wheelchair features. However, because of their technical characteristics, most of these ergometers could only be used inside the laboratory and simulate forward displacements against varying resistances. On the other hand, experimental studies conducted directly on the field were often limited to the measure of a few parameters, thus severely restricting their applications. Thanks to the latest improvements in measurement techniques and signal processing, a new generation of wheelchair ergometers can now be designed that will allow to realize experimental studies in an open environment and to collect biomechanical data in real life conditions. The original ergometer described here is a standard wheelchair equipped with several transducers: a 3D accelerometer and a one-axis gyroscope fixed under the seat; two six-component dynamometers fixed on both rear wheels, which angular positions are measured by two rotating potentiometers; and another six-component dynamometer fixed between the seat and the frame. The 24 signals are sampled at a rate of 500 Hz by a 16-bit A/D card, and sent through a wireless protocol to a remote computer where they are recorded for further processing. In order to validate the complete system, this ergometer has been used to record mechanical parameters of one able-bodied subject performing an 80 m run into an indoor track and field stadium. The main result of this study is that no data were lost during the run, which was the preliminary condition

before with the use of this ergometer in other situations with handicapped persons. Collected data have been then used to calculate the wheelchair's displacements, velocities and accelerations, forces and torques exerted by the user on both handrims and on the seat, evolution of the subject's center of pressure with respect to the wheelchair during propulsion and recovery phases, and external mechanical work and power performed by the user. The great amount of results obtained during this trial cannot be briefly analyzed, although it provides rather interesting information about some parameters rarely considered in wheelchair propulsion. For instance, the differences between right and left pushes in real locomotion, and the evolution of the fore-and-aft distribution of the subject's mass, which has some influence on wheelchair's rolling resistance, thus on the mechanical work produced by the subject, will be largely discussed. The self-contained wireless wheelchair ergometer used in this preliminary study allows to measure numerous mechanical parameters directly on the field. In a near future, these results would be very helpful to personalize rehabilitation methods according to wheelchair users' abilities and activities, and could be used to improve mechanical models of wheelchair locomotion.

40 NET SHOULDER JOINT MOMENTS DURING WHEELCHAIR RELATED ADL IN PERSONS WITH A SPINAL CORD INJURY

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Wheelchair users, especially those with a spinal cord injury (SCI), are subject to serious overuse injuries in the upper extremities (UE). Mechanical load on the UE is one of the risk indicators for overuse problems. The mechanical load around the shoulder during wheelchair propulsion, reaching, and performing a weight-relief lift, in the current study defined as net joint moments, was studied. The purpose of this study was to determine (1) the peak mechanical load in the shoulder during wheelchair propulsion, performing a lift and reaching; (2) which differences in mechanical load exist between wheelchair propulsion and other wheelchair-related ADL; and (3) to what extent mechanical load differs between individuals with a high- or low-level SCI. Three men with high-level SCI (C5-C7) and three men with a low-level SCI (T1–L4) were measured during three tasks: wheelchair propulsion at 3 km/h, three times performing a weight-relief lift and reaching at three heights (0.5, 0.89, and 1.28 m) and with different weights (0, 0.75, and 1.5 kg). External forces of the hand on the wheelchair handrim were determined with an self-developed instrumented handrim wheel (based on AMTI MC61000). Optotrak^{TM} (Northern Digital, Ontario, Canada) was used to collect 3D kinematics of the upper body and wheelchair marker positions and movements. Data were analyzed with Matlab 6.5 (The Mathworks Inc., Natick, MA, USA). Mechanical load was quasi statically calculated around the shoulder joints, with the use of an inverse dynamic approach. Differences in peak shoulder moments within and between tasks, and between lesion level were evaluated with ANOVA for repeated measures ($p < 0.05$). Performing a lift is accompanied with a significantly higher mechanical load compared to wheelchair propulsion ($p = 0.004$) and reaching ($p = 0.007$). Reaching had a significantly higher mechanical load compared to wheelchair propulsion ($p = 0.000$). No significant difference in peak mechanical load in the shoulder was found between high- and low-level SCI was seen in any of the wheelchair-related ADL ($p = 0.920$, 0.415, and 0.713 for wheelchair propulsion, the lift, and reaching, respectively). As expected, all three tasks were significantly different in terms of mechanical load. Performing a weight-relief lift is accompanied with a significantly higher mechanical load than the other ADL, since

bodyweight is to be lifted against gravity. Reaching is accompanied with a significantly higher mechanical load than wheelchair propulsion, probably since on the one hand the torque arm of the external load in reaching is relatively large, while on the other hand wheelchair propulsion was performed at an even and flat treadmill belt surface at a low speed. In contrast to our initial expectations, no significant difference for mechanical load existed between the high- and low-level SCI in any of the three tasks. This implies that the kinematics between the two lesion groups was not essentially different. In the current study, mechanical load was defined as peak net moment. Mechanical load, however, is also determined by the frequency, the direction and the duration of the forces as well. Above that, it is unclear whether previously found strong associations between net moment and joint reaction forces in able bodied subjects are also true for SCI. Therefore, no direct practical conclusions can be drawn from the results of this study in relation to the different levels of injury. Future studies must further substantiate the need for adjustment of training guidelines of the UE during rehabilitation and the specifications of assistive technology and environment.

41 IDENTIFICATION AND ANALYSIS OF THE EFFECT OF CURRENT CLINICAL PRACTICE IN THE AREA OF WHEELCHAIR SEATING/POSITIONING AND MOBILITY

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Over the years, the occupational therapy department within the VU University Medical Center has developed an expertise in the area of wheelchair seating and positioning. This expertise is frequently utilized for clients with complex diagnosis/conditions. By complex diagnosis/conditions, we mean clients with postural and mobility (including transfer) problems, who, as a result of these problems, run the risk to develop or exacerbate current complications such as pain, fatigue, pressure sores, contractures, scoliosis and scoliosis-related breathing difficulties. The result of such complications is a reduced independence in daily life. In the current situation there are many problems with the coordination of services that involve the assessment and supply of wheelchairs and transfer aids/appliances. The reasons are the variety of services involved, the high number of equipment suppliers, the lack of assessment methods and technical support, the lack of a coordinator who can oversee/coordinate the process from assessment to supply. The consequences of the lack of coordination are stress for the client, inefficient use of time, increased costs, unnecessary use of costly services because of reduced independence in daily life. From our practical experience, there is an obvious need for a seating clinic in order to regulate and streamline the practice of assessment, advising and supplying of wheelchairs/seating products for clients with a complex diagnosis/condition. Our goal is to set up a seating clinic in collaboration with The Rehabilitation Centre Amsterdam. The possibility must be present to carry out all the necessary assessments and fittings efficiently, during a short hospital admission (23 days). In order to facilitate this there has to be good interaction between the client and the advisers (suppliers, rehabilitation technician, medical, and allied health professionals). There must also be the possibility to carry out special fittings. Through the use of research, we propose to fully describe the current situation in order to develop an effective strategy to reach our goal of a coordinated and efficient service. Our research questions are: How cost- and quality-effective is the current method of solving seating, positioning and mobility (including transfers) problems for clients with a complex diagnosis/condition? What are the factors which positively and negatively influence the cost and quality of this process? The collaboration between the two centers that already exists facilitates the opportunity to engage in such a project. Expertise in the area of seating and positioning can be drawn from both centers. The results of this project can be used to increase the expertise and the quality of service provided in the area of seating and

positioning. The current manner in which seating and positioning problems are addressed needs to be changed and improved. The research results will offer guideline on what the changes must be and how these changes can be achieved.

42 A SPECIALIST SEATING ASSESSMENT CLINIC: CHANGING PRESSURE RELIEF PRACTICE

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A retrospective review of 50 newly injured and chronic spinal cord injured individuals was undertaken to evaluate pressure relief practice. Transcutaneous tissue oxygenation was carried out as part of a comprehensive seating assessment in the sitting (loaded) and supine (unloaded) positions, as well as during pressure relief. Mean duration of pressure relief required to raise tissue oxygen to unloaded levels was 1 min, 52 s (range 42 s to 3 min, 30 s). These results confirmed the clinical perception that brief pressure reliefs of 15 to 30 s are ineffective in raising transcutaneous oxygen tension ($TcPO_2$) sufficiently. Sustaining the traditional pressure relief by lifting up from the seat for the necessary duration is neither practical nor desirable for the majority of clients. It was found that alternative methods such as forward or sideways leans were more easily sustainable and very efficient.