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CARDIORESPIRATORY CAPACITY IN TETRA- AND PARAPLEGIA SHORTLY AFTER INJURY

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ABSTRACT. **In one hundred patients (86 males, 14 females) with relatively recent spinal cord injuries the oxygen supporting system was evaluated during graded arm ergometry. The patients were assigned according to injury level to 5 subgroups with complete, and to 2 additional groups with incomplete injuries. Mean peak oxygen uptake ($\dot{V}O_2$) was found to be as low as 0.74 l/min in males with complete tetraplegia and 1.9 l/min in patients with conus and cauda lesions. Peak $\dot{V}O_2$ was closely correlated ($r=0.74$) to the injury level. Peak $\dot{V}O_2$ was also closely correlated to peak minute ventilation ($\dot{V}E$) in all groups. In patients with higher injury levels most of the increase in $\dot{V}E$ during maximal exercise was due to an increase in respiratory frequency (fR). In patients with tetraplegia and high paraplegia, arm cranking revealed deficient sympathetic regulation of cardiovascular functions resulting in hypotension. In both the complete and incomplete tetraplegic patients there was a relatively low peak heart rate (fH). Peak fH and $\dot{V}O_2$ varied more in patients with incomplete tetraplegia than in those with complete tetraplegia. Peak $\dot{V}O_2$ in females with mid-level thoracic paraplegia was on the average lower than in males with corresponding injury levels (16 ml/kg/min against 22 ml/kg/min, respectively). Evaluation of cardiorespiratory functions in spinal cord injured patients during high intensity endurance work performed shortly after the injury adds diagnostic and functionally useful information for the design of rehabilitation and should be recommended as clinical routine.**

Key words: Paraplegia, tetraplegia, graded arm exercise, oxygen uptake, heart rate, blood pressure, blood lactate

Today, physical training is generally recommended as a key factor in the rehabilitation of patients with spinal cord injury. However, to be able to evaluate the efficiency of such a rehabilitation, the remaining physical capacity of the patients before the onset of physical active training should be known. Unfortunately, earlier investigations mainly focused upon peak oxygen uptake in paraplegic males with longstanding low level lesions, i.e. after a more or less successful degree of rehabilitation had been achieved (3, 10, 11, 14, 19). Therefore the aim of this study was to acquire and present more information about cardiorespiratory capacity in tetra- and paraplegic patients of both sexes shortly after injury, but before the onset of active physical training.

Since the group of patients investigated comprised almost all injury levels between C5 and S2, it was possible to have the patients subgrouped according to injury level. Another aim of the study was to examine the relationship between injury level and cardiorespiratory capacity in order to assess whether endurance testing can add information of practical importance to the grouping of these patients used in clinical contexts (7) or in sports for the disabled (15).

PATIENTS

Among 200 patients with spinal cord injury hospitalized at the Sunnaas Hospital during the years 1976–1982, 100 satisfied the following selection criteria for this study:

1. The patients were under primary rehabilitation after a recent traumatic spinal cord injury (Table I).
2. They were able to perform arm cranking.
3. They did not suffer from complicating diseases that might interfere with their physical endurance capacity.

The mean age for the 86 males was 29 years and for the 14 females 25 years. They were divided according to injury levels into 5 groups with complete lesions, and 2 groups with incomplete lesions (Table I). Patients with lesions of the conus or cauda equina were included in the CONUS group irrespective of whether their injury was complete or incomplete.

A surgical stabilizing intervention had been necessary after the injury in 30% of the patients, and as many as 84% of the patients were admitted to our hospital with a permanent urinary catheter. At the time of the test, 13 patients suffered from a slight to moderate degree of autonomic dysreflexia, 24 suffered from a slight to moderate degree of orthostatic hypotension, and 20 were taking medicaments against motor spasms.

PROCEDURE AND METHODS

After measuring weight, Hb concentration, and simple spirometric values (Vitalograph), the patients were informed about the intended test procedure in pre-tests. The

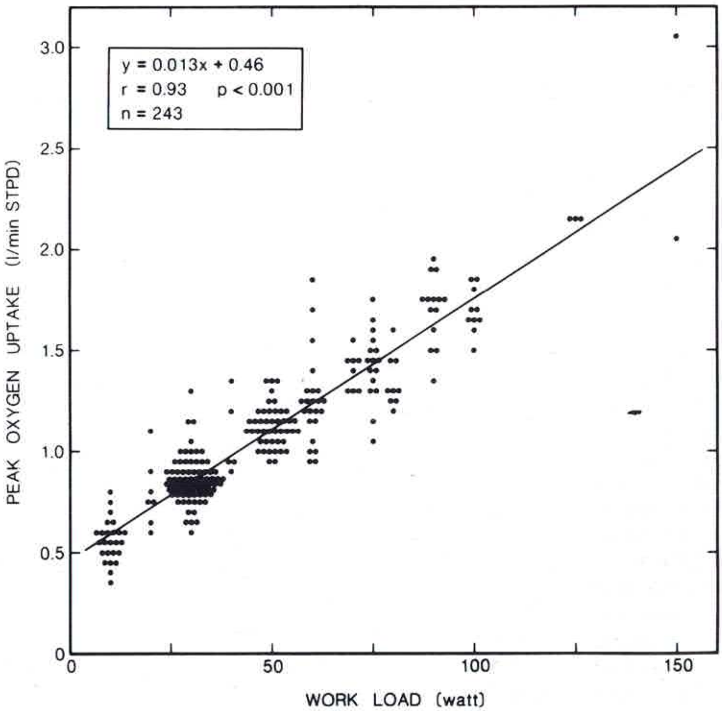

Fig. 1. Relationship between work rate (watt) and oxygen uptake in graded arm exercise in all tested patients.

usual precautions were strictly adhered to before and during the tests proper (20) in which they performed arm work on an electrically braked and load stabilized ergometer (Jaeger, Germany) adapted for arm cranking. Depending on their ability, the patients worked for 1–3 graded submaximal periods lasting 5 min each with short pauses. A maximal work bout lasting 3 min, or until exhaustion then followed the submaximal work loads. Fifteen of the patients could only sustain one work period, which consequently was considered to reflect their maximal capacity.

Heart rate (fH) was assessed from a continuously recorded ECG (Cardioline, V5-lead). Expiratory air was collected in Douglas bags during the last minute of each submaximal period and during the last 30 sec of the maximal load. Minute pulmonary ventilation ($\dot{V}E$ l/min) was calculated from the volume of the air transferred to a calibrated wet spirometer. During the first year of the

Table I. *Groups of patients according to injury level*

Groups of patients	Injury level	Patients in each group		Mean age (years)		Mean interval between injury and test (days)		No. of recordings at max work load: $\dot{V}O_2$		BP		LA	
		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
1. TETRA	C5–C8****	14	0	28		127		7	0	13	0	6	0
2. *HPARA	T1–T6	10	3	24	32	102	71	9	2	6	2	5	3
3. *MPARA	T7–T11	17	6	27	19	94	87	16	6	14	5	14	2
4. *LPARA	T12–L3	19	2	32	20	115	102	19	2	14	2	11	2
5. **CONUS	L4–S2	9	1	33	16	89	138	9	1	8	1	6	2
6. ***ICTETRA	C5–C8	7	2	42	40	115	138	6	1	6	2	5	0
7. ***ICPARA	T1–L3	10	0	27		112		10	0	6	0	4	0

* H, M, L = High-, mid- and low-level injuries.
** Cauda injuries included.
*** Incomplete injuries.
**** The most caudally located unaffected medullary level.
$\dot{V}O_2$ = oxygen uptake, BP = blood pressure, LA = lactic acid concentration.

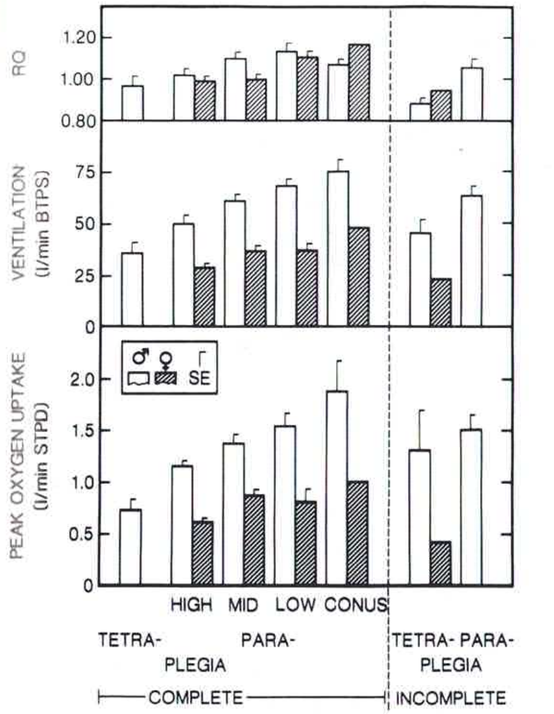

Fig. 2. Mean peak $\dot{V}O_2$, $\dot{V}E$ and RQ values during maximal arm work in male and female patients with complete and incomplete spinal cord injuries.

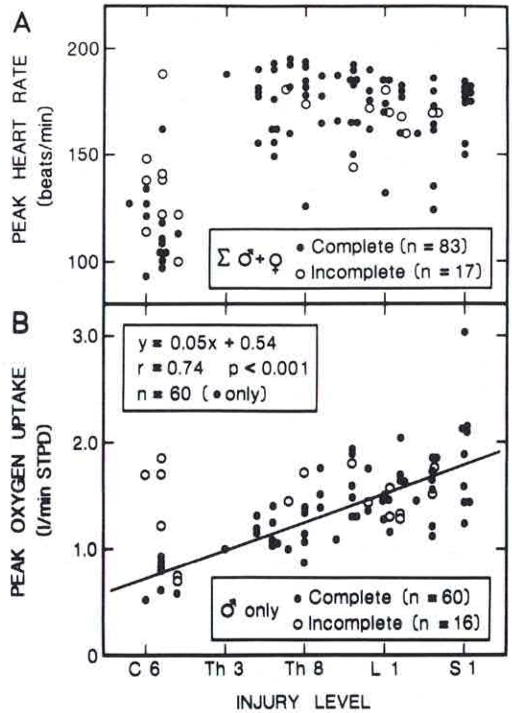

Fig. 3. (*A*) Relationship between injury level and peak heart rate in all tested patients. (*B*) Relationship between injury level and peak oxygen uptake in males with complete (●) and incomplete (○) spinal cord injuries. Regression line, r and p calculated only for complete (●) spinal cord injuries. The results are aligned with the respective equidistantly spaced injury levels (abscissa C5 to S1).

investigation, the expiratory CO_2 and O_2 concentrations were measured with the Scholander apparatus. Later, a rapid CO_2 (infrared) and O_2 (zirconium cell) analysers (Jaeger, Germany) were used. The analysers were calibrated daily by gas mixtures of known CO_2 and O_2 concentrations. Before and immediately after the exercise bouts, blood pressure (BP mmHg) was recorded using an automatically inflatable cuff around the upper arm (Bosomat, 13). Three minutes after maximal exercise bouts 2 ml of venous blood were drawn without stasis from an antecubital vein. Blood samples were immediately precipitated with perchloric acid and analysed for lactic acid (LA) concentrations with an enzymatic method (17).

fH was measured in all patients during the maximal exercise period. Both for technical reasons and because of the condition of the patients peak $\dot{V}O_2$, BP and LA could not be measured in some of the patients (Table I).

Computer aided statistical methods were used for the calculation of arithmetic means ($\bar{x}$) and their standard errors (SE) as well as of linear regressions. The Mann-Whitney test (U-test) was used to calculate the statistical significance of differences between the groups.

RESULTS

There was a linear and rather close relationship between work rate and oxygen uptake (Fig. 1). The mean peak $\dot{V}O_2$ (Fig. 2) was low in all groups compared with healthy persons (8, 18) or patients with old cord injuries (3, 10, 11, 19). It is also evident that endurance capacity was influenced by injury level, the mean peak $\dot{V}O_2$ being, on the average, as low as 0.74 l/min in tetraplegic patients and gradually increasing to 1.9 l/min in patients with conus and cauda injuries (Figs. 2 and 3*B*). The peak $\dot{V}O_2$ showed greater variation in patients with incomplete tetraplegia than in all other groups (Fig. 2). The $\dot{V}CO_2/\dot{V}O_2$ ratios in expiratory air (R, Fig. 2) calculated during the highest work load were high enough to indicate maximal exertion. Respiratory frequencies (fR) were also high (>35 breaths/min in all groups) while tidal volumes (VT) during maximal exercise were low in tetraplegic patients ($\bar{x}$=1.0 l, range 0.81–1.27) as well as in patients with high paraplegia ($\bar{x}$=1.22 l, range 0.93–1.91).

The mean vital capacity in our male patients with high injury levels (TETRA and HIGH PARA) was

Table II. *Statistical testing of differences between the groups of patients*

Groups of patients	n	p fH	W	$\dot{V}E$	VT	$\dot{V}O_2$	BP
TETRA	7						
HPARA	9	0.008***	<0.001***	0.061*	0.221	<0.001***	0.008***
MPARA	16	0.535	0.088*	0.050**	0.019*	0.071*	0.065*
LPARA	19	0.058*	0.101	0.282	0.046*	0.084*	0.777
CONUS	9	0.595	0.264	0.514	0.044**	0.117	0.805
MPARA	16						
MPARA	6	0.581	<0.001***	<0.001***	0.014**	0.001***	0.708

fH = heart rate, w = maximal work load in watts, $\dot{V}E$ = pulmonary ventilation, VT = tidal volume, $\dot{V}O_2$ = peak oxygen uptake, BP = blood pressure. n = includes only patients with measured peak $\dot{V}O_2$.
* $p<0.1$ = probable, ** $p<0.05$ = significant, *** $p<0.01$ = highly significant.

also lowered ($\bar{x}$=3.0 l, range 2.2–4.6) (9, 14, 19). In spite of this, the mean VT/VC ratio for all male patients (18) during maximal exercise was only 0.39 (range 0.20–0.77) instead of the usual >0.50 in healthy subjects.

In all patient groups (males and females) a statistically significant correlation was noted between peak minute ventilation and peak $\dot{V}O_2$ (Fig. 2). Although there was no statistically significant correlation between individual peak fH and peak $\dot{V}O_2$ in any of the completely injured groups, peak fH was sufficiently high in the groups of paraplegic patients to indicate maximal exertion. However, in some of these patients the individual peak fH was below 150 beats per min although they were completely exhausted (Fig. 3*A*). Peak fH in complete tetraplegic patients was markedly lower than in all the other groups (Figs. 3*A* and 4). Mean peak fH was also lower in the patients with incomplete tetraplegia than in all the groups with paraplegia (Fig. 4). However, in patients with incomplete lesions there was a relatively close correlation (r=0.61, p <0.001) between peak fH and peak $\dot{V}O_2$.

Arm exercise induced hypotension in all patients with complete tetraplegia as well as in some patients with high level paraplegia (Fig. 4). Surprisingly, some tetraplegic patients remained relatively unaffected when performing arm cranking in a sitting position, in spite of a systolic blood pressure as low as 60 mmHg and no measurable pulse pressure. No statistically significant correlation was found in any of the groups, between systolic blood pressure measured immediately after maximal exercise, and peak $\dot{V}O_2$.

The mean maximal blood lactate concentrations varied between 5.5 and 11.4 mmol/l (Fig. 4), which is in agreement with earlier reports (10, 11, 19). Still, we found no evidence of significant statistical correlation between the maximal LA values and peak $\dot{V}O_2$ in any group.

The overall cardiorespiratory response pattern during arm work in female patients did not differ qualitatively from that of the males (Figs. 2 and 4). The endurance capacity (peak $\dot{V}O_2$ l/min) of female patients was on the whole lower than that of male

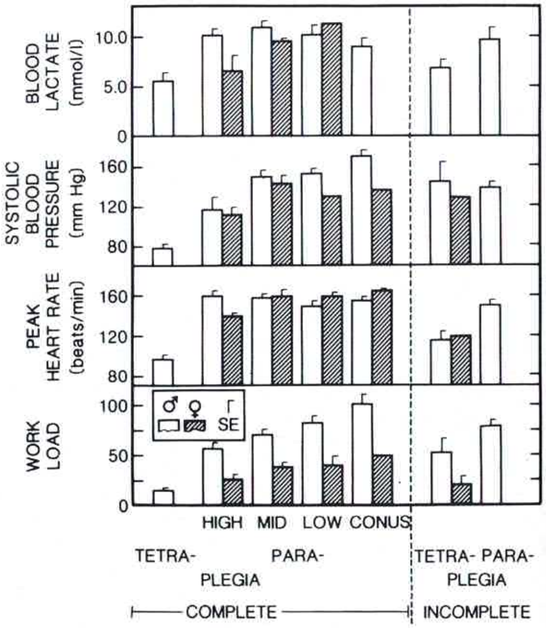

Fig. 4. Mean circulatory (fH, BP) and metabolic (LA) response to maximal work load in arm cranking (watt) in male and female groups of patients with spinal injury.

patients with corresponding levels of spinal injuries. However, when corrected for body weight, the difference between males and females was not statistically significant (Table II).

DISCUSSION

In this study, grouping of patients with spinal cord injuries took into account the efficiency of cardiovascular functions, which becomes increasingly deficient as the injury level shifts cranially from L2 in patients with complete lesions (1, 5) and which may critically influence the oxygen transporting systems (Figs. 2, 3 and 4). It follows that certain injury levels (TH1, TH6, TH10) are more critical than others due to the organization of the sympathetic nervous system (5, 17). However, a combination of several factors could be the cause of low peak oxygen uptake found in some investigated groups:

1. Bed rest and a long period of physical inactivity.
2. Muscle paresis or paralyses below injury level.
3. Deficient autonomic regulation of the cardiovascular system.

Autonomic insufficiency within the cardiovascular system probably contributes to a great extent to the limitation of the endurance capacity in patients with tetraplegia, and at this early stage of rehabilitation, also in patients with high level paraplegia. Peak $\dot{V}O_2$ of disabled athletes competing in the 1972 Olympic games usually was lower than in our study (14). However, these athletes were tested with a synchronous mode of propelling the arm ergometer. In contrast to this, endurance trained athletes competing in the 1976 Games for the disabled had a much higher peak $\dot{V}O_2$ than our patients (19). Thus our results indicate that specific endurance training must be accomplished in order to increase the endurance capacity beyond the low initial capacity condition found in this study in untrained patients.

The net mechanical efficiency in the groups of paraplegic patients approximated 18% during heavy exercise, which is in agreement with earlier reports of arm cranking in both athlete paraplegic patients (16, 19), and healthy persons (8, 18). The values are substantially higher than in wheelchair exercise in untrained subjects (4). Thus arm cranking seems to be an unskilled task which should be recommended early after injury for endurance training in para- and tetraplegic patients prior to wheelchair driving.

The reduced pulmonary function found in our patients with tetra- and high paraplegia is attributed to muscular paresis reducing the expiratory reserve volume (9). Probably this reduction, also reflected as low VT/VC ratios, was not the limiting factor during maximal exercise. However, it should be born in mind that the inspiratory muscles of these patients were working under inefficient mechanical conditions.

The low mean value and the wide spreading of peak fH in the group of tetraplegic patients indicated that although lower than normal the sympathetic facilitation of the heart during heavy exercise varied greatly from one patient to another (1, 5). The low mean systolic blood pressure on increasing work loads in the same group, as well as in some patients with high paraplegia, also reflected the autonomic deficiency. Low blood pressure ultimately leads to low perfusion pressure in the working muscles as well as in the brain, which probably contributed to the rapid development of fatigue that was experienced in many of these patients.

Due to the autonomic deficiency and lability in patients with injury levels higher than TH6, endurance training and endurance events were strongly spoken against by medical authorities as late as in 1972 (2). However, these patients obviously adapt to the cardiovascular insufficiency. Their relatively low cardiac output (11) seems to be more efficiently utilized, probably due to an increased oxygen extraction in the working muscles. In addition medullary sympathetic activity below injury level might increase and become better coordinated to make more blood available for circulation through the working muscles.

The relatively low systemic blood LA concentrations found in some patients reflected the limited amount of actively working muscles. However, in relation to the maximal work loads, the LA values were high enough to indicate maximal exhaustion.

The investigated patients with incomplete tetraplegia were usually of high age and also suffered from extensive pareses in their upper limbs. In addition the sympathetic regulation might have been partially deficient. As a result the measured cardiorespiratory variables generally were low and widely scattered. The patients with incomplete paraplegia had their arm- and upper trunk muscles intact. Their endurance capacity therefore was of the same order of magnitude as in patients with complete mid- and low level lesions. The relatively high peak $\dot{V}O_2$ in the CONUS group might indicate the positive influence of active muscle mass in the lower extremities during arm work.

Lower endurance capacity as well as lower vital capacity in the female patients were related to smaller body dimenstions (Table I, Figs. 2 and 4). However, when corrected for differences in body weight the differences in peak $\dot{V}O_2$ between the male MPARA group and the female MPARA group were smaller than corresponding differences found in healthy persons (8). Female wheelchair athletes have achieved very high endurance capacities and performed excellently in endurance events (19). Therefore no precautions should hinder either endurance testing or training of female patients.

The differences in cardiorespiratory functions between the groups of patients emphasize that the capacity of the oxygen transporting system should be routinely evaluated to enlarge the neurologically based information about the patient. Such testing also contributes to the design and evaluation of physiologically based training programmes and makes it possible to compare the endurance capacity of the patients with the energetic needs of daily life activities (6, 12). In sports for the handicapped such evaluation will be of special importance to patients with injury levels corresponding to a transitional cord zone between two classes.

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