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Effect of Wheelchair Ergometer Training on Spinal Cord-injured Paraplegics

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The purpose of this study was to investigate the effect of wheelchair ergometer training on spinal cord-injured paraplegics. Eleven male paraplegics with a mean age of 30.9 years (range, 20 to 49 years) participated in the wheelchair ergometer training for the period of 5 weeks. The mean peak heart rate, the mean peak systolic blood pressure and the mean time required for 100m wheelchair propelling at resistance level 1 were significantly decreased at the end of 5 weeks of training as compared with those at pre-training. There was no statistically significant difference in pulmonary function test at pre- and post-training. The peak torque of shoulder flexor and the total work of shoulder flexor and extensor at 180°/sec after training were increased more significantly than those prior to the training. In accordance with the findings as revealed above, it is deemed that the endurance and strength of the upper body and the cardiac fitness for spinal cord-injured paraplegics may be improved by the wheelchair ergometer exercise.

Key Words: Wheelchair ergometer, cardiac fitness, endurance

The cardiorespiratory fitness of wheelchair-dependent individuals with spinal cord-injury is limited by a low maximal heart rate, low stroke volume and a poor peripheral circulation (Knutsson et *al.* 1973; Zwiren and Bar-Or 1975). In addition, wheelchair users, as compared with the abled, have a small volume of active muscles, and therefore are apt to feel fatigue easily, even by daily locomotor tasks. Because a series of wheelchair activities with sufficient intensity and duration for improving or maintaining cardiorespiratory fitness and endurance is difficult to be carried out by wheelchair-dependent individuals due to above reasons, the exercise capacity would be decreased. Carrying out maximal and submaximal exercise tests on eleven wheelchair-dependent athletes with arm crank ergometer, Zwiren and Bar-Or (1975) reported that the maximal oxygen consumption was not only significantly higher in wheelchair-dependent athletes than in wheelchair-dependent sedentary individuals but also the maximal oxygen consumption did not differ significantly between wheelchair-dependent athletes and able-bodied athletes. Thus it is generally agreed that cardiorespiratory fitness for wheelchair-dependent individuals could be improved with an appropriate exercise training program. Therefore effective exercise programs have been necessitated in the process of the comprehensive rehabilitation therapy for wheelchair-dependent individuals.

Arm crank ergometer and wheelchair ergometer are the instruments most commonly used to assess the exercise capacity and improve cardiorespiratory fitness and endurance of wheelchair-dependent individuals (Pitetti *et al.* 1987; Shephard, 1991). The superiority between these two exercises has been differently reported by different authors.

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Sawka *et al.* (1980) conducted the exercise test using arm crank ergometer and wheelchair ergometer on wheelchair-dependent and able-bodied subjects. The values of oxygen uptake, pulmonary ventilation and systolic blood pressure at the same work load were lower for arm crank ergometer exercise than for wheelchair ergometer exercise. These results suggest that wheelchair ergometer exercise elicits greater cardiorespiratory stress than arm crank ergometer. Wicks *et al.* (1977 ~1978) and Glaser *et al.* (1980) reported that the mechanical efficiency was substantially higher for arm crank ergometer than for wheelchair ergometer. They concluded that arm crank ergometer was less stressful to the cardiorespiratory system than wheelchair ergometer.

The first reported exercise training study relative to wheelchair ergometer was conducted by Engel and Hildebrandt (1973). The subjects consisted of thirteen male paraplegics. Wheelchair ergometer exercise was conducted once or twice a week for 16 weeks. The results showed a significant decrease of heart rate. As the notion of exercise specificity was brought in, from the point of view that wheelchair ergometer exercise mimicked the daily locomotor tasks of wheelchair users closely, it has been widely used for assessing and evaluating exercise capacity and cardiorespiratory fitness for wheelchair-dependent individuals (Glaser *et al.* 1978~1979; Glaser *et al.* 1981; Shephard *et al.* 1991). There are three kinds of wheelchair ergometer, namely the mounting of a wheelchair on a modified inclined treadmill, on low-friction rollers, and the coupling of a wheelchair to a cycle ergometer or purpose-built ergometer (Dreisinger and Londeree 1982).

Glaser *et al.* (1981) conducted wheelchair ergometer exercises for thirteen able-bodied female volunteers. Of them, seven were selected to participate in wheelchair ergometer exercises consisting of 2 training sessions per week for a total of 10 sessions during the 5-week study. Following 5-week wheelchair ergometer exercise, submaximal heart rate, pulmonary ventilation and oxygen uptake of the seven wheelchair ergometer exercise group were found to be significantly lower during the post exercise test. Thus, they concluded that wheelchair ergometer exercise might have contributed to adaptation of upper body muscle, improved cardiorespiratory function and higher level of skill for wheelchair propulsion. Miles *et al.* (1982) tested eight male wheelchair athletes prior to and 6 weeks after training using wheelchair ergometer which coupled a wheelchair to a cycle ergometer. They reported that maximal exercise ventilation and peak oxygen uptake increased significantly, although the static lung volumes were not changed. They concluded that the wheelchair ergometer exercise was useful for the improvement of cardiorespiratory fitness.

However, the report on the effect of wheelchair ergometer exercise applied to spinal cord-injured paraplegics was scarce, and little research has been conducted using wheelchair ergometer with the form in which the wheelchair was put on rollers.

The purpose of this study was to evaluate the cardiorespiratory function and exercise capacity of spinal cord-injured paraplegics using wheelchair ergometer with the form in which the wheelchair is put on rollers, hereafter to help in the comprehensive rehabilitation therapy of spinal cord-injured paraplegics.

SUBJECTS AND METHODS

Among complete spinal cord-injured paraplegics who visited the Department of Rehabilitation Medicine, Yonsei University College of Medicine, eleven male patients who had no cardiorespiratory disorders and whose disability duration was over 6 months were selected as subjects.

The seat width of the wheelchair (Quickie Designs Inc., Fresno, California, U.S.A.) was 16 inches. The exercise was carried out after stabilizing the trunk with a belt in the state of removing both arm rests. The method of wheelchair propulsion was to apply force to the hand rims by both hands simultaneously.

The exercise was carried out using wheelchair ergometer, Ergotronic 4000 (Sopur GmbH, Heidelberg, Germany), in which the wheelchair was put on rollers. Subjects completed wheelchair ergometer exercise training three times a week for 5 weeks.

Prior to the beginning of each exercise, all subjects performed warm-up submaximal exercise for two minutes at a speed of 3 km/hr at resistance level 0 on wheelchair ergometer. After the warm-up exercise, subjects performed wheelchair ergometer exercises.

Each exercise session was 30 minutes in total, consisting of 3 sets of 10 minute exercises with 5 minutes rest between sets. Subjects were encouraged to maintain a velocity of more than 3 km/hr at each resistance level. The resistance level was increased if subjects could run more than 10 minutes at each resistance level and would not meet the criteria of exercise interruption at each bout. The criteria of exercise interruption was applied as follows; 1) when the subjects could not maintain a velocity of over 3 km/hr at each resistance level, 2) when the heart rate reached above the target heart rate that elicited 80% of their predicted age-adjusted maximal heart rate (220-age), corrected (−10 beat /min) for arm exercises. It was known that the maximal heart rate averages approximately 11 beats/min lower for arm than for leg exercises (Stenberg *et al.* 1967). In this study, the age-adjusted maximal heart rate was used by calculating (220)-(age)-(10) beats/min (Glaser *et al.* 1981).

Before and after the 5-week training period, pulmonary function test was performed with MasterLab (Erich Jaeger GmbH & Co. KG, Wurzburg, Germany), and heart rate, resting blood pressure and blood pressure at 100m wheelchair propelling at resistance level 1 were measured. Further, the time required for 100m wheelchair propelling at resistance level 1 was measured. The heart rate was determined with Sport Tester PE 300 (Polar Electro KY, Kempele, Finland). In addition, before and after the 5-week training period, with the Isokinetic Rehabilitation and Testing System, Model No. Cybex 340 (Cybex Division of Lumex Inc., New York, U.S.A.), subjects performed 30 practice repetitions for shoulder and elbow flexion and extension at a speed of 180°/sec, bilaterally. Data were collected for the peak torque and the total work. Testing protocol, testing positions, and joint stabilization conformed to guidelines outlined in the Cybex testing manual. A Cybex 340 printer and dynamometer were interfaced with the cybex 340 computer for analysis of test results. For statistical analyses of these data, the Wilcoxon signed rank test was used to investigate the effect of wheelchair ergometer training on spinal cord-injured paraplegics at the end of the 5-week training period.

RESULTS

Characteristics of the subjects

Characteristics of the subject are presented

Table 1. Characteristics of the subjects

Subject	Age(yr)	Height(cm)	Weight(kg)	Duration of disability(mo)	Cause of handicap	Level of lesion
1	29	164	52	12	Falls	T_{12}
2	34	174	74	6	Traffic accident	T_8
3	20	180	69	12	Traffic accident	T_{11}
4	32	172	58	24	Falls	T_{12}
5	26	177	58	24	Falls	T_{12}
6	27	165	58	36	Falls	T_{12}
7	39	181	62	12	Falls	T_{12}
8	28	162	50	48	Traffic accident	T_{11}
9	49	174	73	12	Falls	T_{11}
10	32	174	74	16	Falls	T_{12}
11	24	174	72	24	Traffic accident	T_9
Mean±SD	30.9±7.9	172.5±6.3	63.7±9.0	20.6±12.5		

in Table 1. The mean (±SD) age was 30.9±7.9 years, ranging from 20 years to 49 years.

Physiological response to wheelchair ergometer exercise

When running 100m at resistance level 1 of wheelchair ergometer, the mean peak heart rate, the mean peak systolic blood pressure and the mean time required for 100m wheelchair propelling at resistance level 1 were significantly decreased at the end of 5 weeks of training as compared with those at pre-training ($p<0.05$) (Table 2). There was no statistically significant difference in the mean resting heart rate, the mean resting systolic and diastolic blood pressure and the mean peak diastolic blood pressure when running 100m at resistance level 1 of wheelchair ergometer at pre- & post-training.

Table 2. Physiological responses to wheelchair ergometer exercise (n=11)

Physiological response	Befor training	After training
Resting HR (beats/min)	79.7±6.1	78.2±7.2
Resting systolic BP (mmHg)	125.5±12.1	123.6±11.2
Resting diastolic BP (mmHg)	81.8±6.0	80.0±6.3
Peak HR (beats/min)	175.6±1.6	163.8±8.0*
Peak systolic BP (mmHg)	191.8±7.5	175.5±6.9*
Peak diastolic BP (mmHg)	75.5±5.2	73.6±6.7
Time[1] (sec)	69.7±5.1	57.3±2.3*

Values are given as mean and standard deviation.
*$p<0.05$
Time[1]: time required for 100m wheelchair propelling

Pulmonary function test before and after 5 weeks of training

There was no statistically significant difference in pulmonary function test at pre- & post-training (Table 3).

Isokinetic test before and after 5 weeks of training

As the result of carrying out the isokinetic

Table 3. Pulmonary function test before and after 5 weeks of training (n=11)

PFT	Before training (% predicted)	After training (% predicted)
FVC (L)	4.4±0.8	4.3±0.7
	(92.5±14.0)	(91.3±11.6)
FEV_1 (L)	3.8±0.6	3.8±0.5
	(94.6±11.6)	(94.2±9.3)
MMEF (L/sec)	4.1±0.9	4.2±1.0
	(87.8±14.2)	(90.4±18.1)
PEF (L/sec)	10.2±1.7	9.9±1.7
	(110.8±16.7)	(107.1±15.3)
$PEF_{25\%}$ (L/sec)	8.6±1.5	8.5±1.3
	(109.4±17.0)	(108.3±14.8)
$PEF_{25\%}$ (L/sec)	2.0±0.6	2.2±0.6
	(86.3±18.7)	(94.4±23.4)

Values are given as mean and standard deviation.
FVC: forced vital capacity
FEV_1: forced expiratory volume in 1 sec
MMEF: maximum midexpiratory flow
PEF: peak expiratory flow
$PEF_{25\%}$: peak expiratory flow at 25% of vital capacity
$PEF_{75\%}$: peak expiratory flow at 75% of vital capacity

Table 4. Results of isokinetic test before and after 5 weeks of training (n=6)

Muscle group	Peak torque		Total work	
	Before training	After training	Before training	After training
Shoulder flexor	30.9±6.8	39.3±7.0*	1,149.3±466.9	1,602.8±425.5*
Shoulder extensor	45.6±5.6	48.4±10.2	1,801.3±332.5	2,241.5±34.8.0*
Elbow flexor	25.8±6.4	28.6±5.1	824.8±228.1	952.3±216.1
Elbow extensor	26.4±5.0	29.7±5.3	1,030.9±266.2	1,180.4±239.9

Values are given as mean and standard deviation (ft-lbs).
*$p<0.05$

exercise test in the flexor and extensor of shoulder and elbow at pre- and post-training, the mean peak torque and the mean total work tended to increase after 5 weeks of training. Especially, the mean peak torque of shoulder flexor was shown with significant increase as recording 30.9±6.8 ft-lbs before exercise and 39.3±7.0 ft-lbs after exercise ($p < 0.05$) (Table 4). The mean total work significantly increased from a pre-training value of 1,149.3±446.9 ft-lbs to a post-training value of 1,602.8±425.5 ft-lbs for elbow flexor and from a pre-training value of 1,801.3±332.5 ft-lbs to a post-training value of 2,241.5±348.0 ft-lbs for elbow extensor ($p < 0.05$) (Table 4). But there were no statistically significant differences in the mean peak torque and the mean total work for flexors and extensors of shoulder and elbow at the end of 5 weeks of training period.

DISCUSSION

As the cardiorespiratory fitness and endurance of wheelchair-dependent individuals are lower and the available muscles are subject to be restricted as compared with normal persons, they are apt to feel fatigue easily and it is known that the improvement of their cardiorespiratory fitness could not be brought about only by daily locomotor tasks of wheelchair-dependent individuals (Hildebrandt *et al.* 1970; Sedlock *et al.* 1988). However, because of the widely-known fact that their cardiorespiratory fitness could be improved through an appropriate exercise (Knutsson *et al.* 1973; Pollock *et al.* 1974; Zwiren and Bar-Or, 1975; Sedlock *et al.* 1990), a series of effective exercise programs have been necessitated in the process of rehabilitation therapy for wheelchair-dependent individuals (Glaser *et al.* 1981).

The wheelchair ergometer would provide wheelchair dependent disabled persons with the similar situations faced by them in their actual life. Therefore, since the concept of exercise specificity was introduced, the wheelchair ergometer has been broadly used for the evaluation of exercise capacity, cardiorespiratory fitness and endurance training of wheelchair dependent individuals. However, the guidelines for exercise duration, intensity, frequency for cardiorespira-tory fitness and endurance training have not been established. Also, the specific exercise programs related to the form of each respective wheelchair ergometer have become necessitated. When performing the exercise using wheelchair ergometer in order to improve the cardiorespiratory fitness and endurance of wheelchair dependent disabled persons, the guidelines for exercise duration range widely from 4 weeks to 24 weeks depending on each study. Glaser *et al.* (1981) reported the significant decrease of heart rate and the significant increase of power at the same amount of work load after 5 weeks of wheelchair ergometer exercise training. Dicarlo and Taylor (1983) reported a 67% improvement of maximal oxygen uptake for spinal cord injured paraplegics after 5 weeks of arm crank ergometer exercise. Further, Sedlock *et al.* (1988) reported a decrease of heart rate and blood lactic acid level in the submaximal exercise test using wheelchair ergometer followed by the completion of arm crank ergometer exercise for the period of 5 weeks.

Therefore, the author established a 5-week exercise program for evaluating the effect of a short term exercise program by considering the decreasing phenomenon of the patient's motivation in accordance with the passage of exercise duration and the above bibliographic review.

The exercise intensity was varied in each study report. Hooker and Wells (1989) carried out the wheelchair ergometer exercise for 8 weeks in order to determine the exercise intensity to demonstrate the maximal improvement of cardiorespiratory fitness. Two spinal-cord injured groups performed wheelchair ergometer exercise at the intensity of 50~60% and 70~80% of the maximal heart rate, respectively. They reported that the exercise intensity at 70% maximal heart rate was the threshold intensity needed to elicit training benefits in spinal cord-injured persons. Currently, in the wheelchair ergometer exercise for improving cardiorespiratory fitness and endurance, the exercise intensity at 60~70% maximal oxygen uptake or 70~80% maximal heart rate have been broadly utilized (Shephard, 1988).

As for the exercise frequency, interval training programs with 2~3 workbouts per week have been widely adopted for exercise training on the subjects of disabled persons, because such exercise programs have the advantage of being relatively short exercise bouts, being less boring, and more closely resembling the intermittent nature of daily activity patterns. Glaser *et al.* (1981) reported that submaximal heart rate, pulmonary ventilation and oxygen uptake responses were significantly lower after 5 weeks of wheelchair ergometer exercise twice a week at 80% maximal heart rate. They concluded that applying the concept of interval training to wheelchair exercise might substantially improve the performance and fitness characteristics of wheelchair users and such an exercise program could reduce the relative stresses of wheelchair locomotion and lead to a higher level of rehabilitation.

The duration of exercise required to elicit a significant training effect varies inversely with the intensity; the greater the intensity, the shorter the duration of exercise necessary to achieve favorable adaptation and improvement in cardiorespiratory fitness. The initial exercise prescription should include sessions of moderate duration and intensity, such as 20 to 30 minutes and 40% to 70% of aerobic capacity (Vo_2max). And in the case of performing an exercise below the duration of 20 minutes, the effect of training would be decreased (Shephard, 1977).

Since an additional amount of energy is necessary for maintaining the posture of the trunk when the wheelchair dependent disabled persons perform an exercise, oxygen uptake is increased. Further, because of the restriction of available muscles as compared with the abled persons, the wheelchair dependent disabled persons would be subject to feel local muscle fatigue before the expected training effect appears. In this study, the lesions of 9 subjects among the total 11 subjects were T_{11} and T_{12} complete spinal cord injury. Therefore, the subjects could reduce the energy consumption for maintaining posture while performing the wheelchair ergometer exercise. In order to minimize the recovery effect of muscle strength from the initial deterioration of muscle strength due to the bed rest at the initial stage of illness, the author applied the wheelchair ergometer exercise to the subjects whose period of illness was more than 6 months and whose mean disability duration was 20.6 months.

As there has not been any report on the effect of exercise with the Ergotronic 4000 - a wheelchair ergometer used in this study - up to the present, the author integrated the result of the preliminary study for 4 spinal cord-injured paraplegics and the related bibliographic review. The author established 5 weeks of exercise with an exercise frequency of three times a week and exercise duration of 30 minutes. The exercise was designed to maintain a velocity of over 3 km/hr in order to reach the target heart rate corresponding to 80% of the maximal heart rate calculated by the method of Stenberg *et al.* Because the subject's motivation would be lowered as time passes, the relatively short period of exercise (5 weeks of exercise) was established in this study.

It was thought that the Ergotronic 4000 made the visual feedback effect by providing velocity and exercise duration on the panel during the exercise. Also, therapists encouraged subjects continuously throughout the exercise period to prevent them from feeling tedious.

The heart rate during the exercise would increase in proportion to exercise intensity. Such an increase of heart rate would be due to the activation of the sympathetic nervous system and the decrease of activity of the parasympathetic nervous system - vagus nerve. The heart rate at the same work load would be reduced through the exercise training of long duration. In other words, it means that the duration for reaching maximal heart rate is prolonged and the exercise with a more intensive workload could reach the maximal heart rate. The lesser the range of variation for the heart rate during the exercise is, the better cardiorespiratory function and endurance is begotten. Therefore, it may be considered to have a reserved capacity that is able to do more intensive exercise (Kang, 1988). Engel and Hildebrandt (1973) reported a 14~16% reduction of the heart rate at the same workload during the submaximal exercise test after 14 weeks of wheelchair exercise on the subjects of 13 spinal cord-injured paraplegics. Knuttson *et al.* (1973) also reported that there was no significant difference in the heart rate at the same work load of submaximal exercise tests before and after 6 weeks of arm crank ergometer exercise on the subjects of 10 paraplegics. In this study, there was a 9.3% reduction of the mean peak heart rate after 5 weeks of wheelchair ergometer exercise (from 175.6 beats/minute before the exercise to 163.8 beat/minute following the exercise). It is deemed to be attributable to such facts as the improvement of cardiorespiratory fitness, the increase of technique to wheelchair propulsion and the adaptation of upper extremity muscles from the result of wheelchair ergometer exercise training. Thus, it is suggested that the stress by daily locomotor tasks of wheelchair-dependent individuals could be reduced by the wheelchair ergometer exercise. Further, the mean resting heart rate is reduced through exercise training by increasing the tone of the vagus nerve and the contractibility of the cardiac muscle. The cardiorespiratory fitness and endurance could be assessed with the resting heart rate (Kang, 1988). In the meantime, other reports revealed that it would be difficult to explain the improvement of cardiorespiratory function with bradycardia at rest because of a large variation of the resting heart rate (Pollock *et al.* 1974; Hullemann *et al.* 1975).

Although there was no significant difference in the resting heart rate at pre- and post-exercise training (from 79.7 ± 6.1 beats/minute at pre-test to 78.2 ± 7.2 beats/minute at post-test), the standard deviation of heart rate was not too large and it was also considered that the 5-week exercise duration would be regarded as being too short a duration to induce a decrease of the resting heart rate. Therefore, a series of studies for the sufficient duration and intensity of exercise to bring about the bradycardia at rest are considered necessary.

Systolic and diastolic blood pressure after exercise were known to be either slightly decreased or not changed at the same work load during the endurance exercise. In this study, the mean peak systolic blood pressure for 100m wheelchair propelling was significantly decreased, but there was no statistically significant decrease in the mean diastolic blood pressure for 100m wheelchair propelling and the mean resting blood pressure at the end of 5 weeks of training. It is a known fact that diastolic blood pressure is less changed than systolic blood pressure through exercise, and in this study there is no significant difference between diastolic blood pressure at pre- and post-training.

Although FVC (forced vital capacity) of athletes is not significantly increased by exercise, FEV_1 (forced expiratory volume in 1 second) is increased by exercise. Also, PEF (peak expiratory flow), $FEF_{25\%}$ (forced expiratory flow 25%) and PIF (peak inspiratory flow) of athletes is higher than those of non-athletes. Such results were induced by the reduction of airway resistance, an increase of lung compliance and the development of respiratory muscle (Kang, 1988). Miles *et al.* (1982) reported that the pulmonary ventilation was significantly increased after 8 weeks of wheelchair ergometer exercise with three times per week for wheelchair-dependent disabled persons, although there was no difference in vital capacity, inspiratory reserve volume and residual volume. In this study, the pulmonary function test at pre-exercise was within normal range for every 11 subjects, and there was no significant difference in the pulmonary function test at pre- and post-training.

Davis and Shephard (1990) reported that prime movers during the exercise of arm crank ergometer or wheelchair ergometer are shoulder flexor and elbow extensor. And they further reported that the improvement of muscle strength was most prominent in shoulder flexor and elbow extensor after 16 weeks of isokinetic exercise training using arm crank ergometer on 11 spinal cord-injured paraplegics. In addition, it is known that the increase of muscle strength that appeared in the initial stage of the exercise is largely attributed more to the change of the fiber recruitment pattern than to the hypertrophy of muscle fibers (Shephard,1988), although the muscle biopsy findings of the wheelchair-dependent disabled show that the proportion of type II muscle fiber is high and the diameter of skeletal muscle fibers is 2~3 times as large as those of the abled (Taylor *et al.* 1979). In this study, the peak torque and the total work had the tendency to increase in the flexor and extensor of shoulder and elbow at the end of the 5-week training period. In particular, the peak torque of shoulder flexor was significantly increased, and it was consistant with the report by Davis and Shephard (1990). In this study, the reason that a significant increase of peak torque in the elbow extensor was not demonstrated was considered to be that an insufficient number of subjects took the isokinetic exercise test.

It is regarded that the reduction of mean time required for 100m wheelchair propelling at the end of the 5-week training period is attributable to the increase of muscle strength in the prime movers for the wheelchair propelling and the improvement of mechanical efficiency.

As having observed for the above results, it is reasonable to think that if the duration, intensity and frequency of wheelchair ergometer exercise would be approprate, the endurance and strength of the upper body and cardiac fitness of the spinal cord-injured paraplegics may be improved by the wheelchair ergometer exercise, and a wheelchair ergometer exercise program to obtain maximal effect should be established in the future.

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