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Cardiorespiratory status and movement capabilities in adults with limb amputation

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Abstract—Two hundred and thirty subjects with various levels of upper and lower limb amputation were examined with regard to cardiac and respiratory functions. The subjects were examined at rest and in balanced wheelchair ergometer testing. Noncontinuous step-by-step increased loading was performed. The data given are for age-group 20–40 who sustained traumatic amputation and suffered no prior respiratory or circulatory disease.

Subjects after above-knee (AK), bilateral AK or AK plus below-knee amputation) showed a loss of the reaction of an adequate systolic output rise in wheelchair ergometer testing. In the adults with amputation, the increase of minute stroke volume occurred solely at the expense of heart rate. The contractile capacity of myocardium was decreased. Cardiac indicator value in subjects with AK or bilateral AK amputation in submaximal exercise training appeared to be lower than in the control group.

A reduced work capacity takes place in subjects after body mass loss. The maximal oxygen intake in subjects with bilateral lower limb amputation was less than in the control group. The breaking of correlation interrelationships between working capacity indicators was revealed in the subjects with bilateral lower limb amputation.

The adults with upper limb amputation showed a reduction in pulmonary ventilation. During exercise training, the capacity for adequate pulmonary ventilation was lost in the above-mentioned subjects.

This research demonstrates that movement capabilities in adults with amputation depend not on the level of amputation and residual limb condition, but to a great extent upon the dynamic capabilities of the cardiac and respiratory muscular systems' ability to adjust to the limb loss.

Key words: *adults with limb amputation, cardiac and respiratory system, exercise training, medical supervision, movement capabilities, rehabilitation.*

INTRODUCTION

Limb amputation, reduction of body mass and vascular channel, hypokinesis, and marked disturbances in static-dynamic function of locomotory system influence the homeostasis drastically. Subjects with amputation show disturbances in blood circulation and metabolism, reduced physical working capacity, and reduced tolerance for workload (1–6). Thus, prosthetic fitting and rehabilitation in subjects after limb amputation are complicated by the above-mentioned factors.

The efficiency of prosthetic rehabilitation in adults with lower limb amputation depends not only on the amputation level, anatomic and functional condition of the amputated limb, and quality of the prosthetic appliances, but on cardiorespiratory function as well. In this connection, the motor activity is essential to the adults with limb amputation as a means of keeping up the body systems, providing a preventive treatment of hypokinetic state, and keeping up the vital tone. In this respect, exercise training and sports are considered to be of essential value (7–9). However, it should be noted that most papers on physical aspects and estimates of physical fitness reveal problems in adults with spinal cord

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injuries having amputation (9–13); whereas, the problems of subjects with only amputation are revealed to a lesser extent (12, 14–16). The medical problems of regular exercise training and sports in subjects with limb amputation have not been adequately explored. The volume of exercise loading and estimates of physical fitness (in the course of medical supervision) are defined with methods and criteria developed for nondisabled subjects, the post-amputation changes in a subject are not taken into account.

This paper seeks to 1) examine responses of the blood circulation system and external respiration to balanced exercise training in adults with amputation (various levels of amputation); 2) evaluate motor capabilities; 3) evaluate allowable exercise training; and, 4) evaluate physical fitness in adults with amputation.

METHOD

Tests of cardiac and respiratory functions were performed at rest as well as in balanced wheelchair ergometer testing. As indicated earlier, lower limb subjects with amputation performed ergometer testing in the form of forearm pedaling while in a seated position; upper limb subjects in the form of foot pedaling. A noncontinuous step-by-step-increased loading was performed. The duration of each loading was 3 minutes (at 3-minute intervals). The loadings were selected by using the B.P. Prevarsky method (17) which provides an approach differentiated with respect to loadings. Weight, age, and sex of subjects tested were taken into consideration: the proper maximal oxygen intake (PMOI) was calculated for each subject by using a special method developed by B.P. Prevarsky. The power of exercise training loading corresponding to 20, 35, 50, and 75 percent of PMOI was calculated (light loading, two intensive loadings, and submaximal loading, respectively). The average values of power of exercise loadings for wheelchair ergometry are given in **Table 1.**

All subjects with amputation who were examined were divided into five groups depending on the level of amputation:

- group I-subjects after unilateral amputation at shoulder level
- group II-subjects after bilateral amputation at shoulder level

Table 1.
Values of wheel ergometry exercise training.

Group and Type	EXERCISE TRAINING I 20% PMOI	II 35% of PMOI	III 50% of PMOI	IV 75% of PMOI
Control Group I	27.7 ± 0.7	65.3 ± 1.3	110.7 ± 2.7	176.0 ± 4.0
Unilat amp at shoulder level	28.7 ± 0.6	67.4 ± 1.1	115.0 ± 1.9	182.2 ± 3.4
Bilat amp at shoulder level	26.0 ± 0.8	63.2 ± 1.4	106.2 ± 2.7	171.6 ± 3.9
Control Group II	27.8 ± 0.7	65.7 ± 1.4	111.4 ± 2.8	172.8 ± 5.6
Unilat BK amp	28.2 ± 0.5	66.4 ± 0.9	112.8 ± 1.9	179.2 ± 2.9
Unilat AK amp	27.8 ± 0.6	65.6 ± 1.3	110.0 ± 2.2	176.8 ± 3.9
Bilat AK amp and AK + BK amp	28.5 ± 0.5	67.0 ± 1.0	114.0 ± 2.1	181.0 ± 3.1

In submaximal exercise training the subjects with amputations were not usually able to perform the whole exercise because of fatigue.
Exercise periods: Control group II = 2.05 ± 0.11 min;
BK amp = 1.89 ± 0.12 min; AK amp = 1.79 ± 0.13 min; bilat AK and AK + BK amp = 1.13 ± 0.15 min.
PMOI = proper maximal oxygen intake; unilat = unilateral; bilat = bilateral; amp = amputation; AK = above knee; BK = below knee

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• group III-subjects after unilateral below-knee (BK) amputation
• group IV-subjects after unilateral above-knee (AK) amputation
• group V-subjects after bilateral AK amputation or after bilateral AK plus BK amputation.

The examination of cardiac and respiratory functions was carried out by electrocardiography (ECG), polycardiography (PCG), tachooscillography (TOG), and echocardiography (EchoCG) M-operating condition. The examination of external respiration was undertaken by spirography and pneumotachometry. Synchronous recording of PCG, TOG, and EchoCG was performed 1) during rest, 2) after each step of loading, and 3) in the post-exercise period after 3, 6, and 10 minutes. The recording of external respiration by spirography and pneumotachometry was performed in a similar manner. The evaluation of maximal oxygen intake (MOI) was undertaken by Astrand nomogram, based on exercise value made and heart rate value during exercise, the pulse rate being measured during the above exercise (18).

Statistical data processing was carried out by the method of analysis of variance (ANOVA).

PROCEDURES

A combined program of research of blood circulation and external respiration in 230 subjects (various levels of amputation) was performed. Male subjects aged 20 to 40 years were examined (159 subjects, 69.1 percent, aged 20–29 years; 71 subjects, 30.9 percent, aged 30–40 years); of which 147 had lower limb amputation (52 subjects with BK; 56 subjects with AK; 19 with bilateral BK and AK; 20 with bilateral AK) and 83 adults with upper limb amputation (49 with unilateral amputation at shoulder level and 34 with bilateral amputation at shoulder level). All subjects sustained traumatic amputations (i.e., caused by traumatic injury). The most common causes of lower limb amputation were 1) traumatic injuries (55.8 percent), 2) injuries caused by explosive mines (27.8 percent), and 3) gunshot injuries (6.8 percent), in that order. The most common causes of upper limb amputation were 1) traumatic injuries of mechanical character (53.0 percent), 2) injuries caused by electric devices (32.5 percent), and 3) gunshot injuries (13.2 percent). Among the traumatic injuries of mechanical character were injuries caused by railway accidents and road transport accidents. In most cases, the injuries were inflicted during the Afghan war.

The study was done during various post-amputation periods: after 4 months and later, when the after-effects of the acute period had passed. The post-amputation periods are shown in **Table 2** which shows that the majority of subjects were examined long after amputation and thus had already adapted to changed homeostasis. Ninety-five subjects were in their post-amputation period (no prosthesis) and 135 had prior use of prostheses. None of the subjects

Table 2.
Average values of power of exercise loadings for wheelchair ergometry.

Time since Amputation	SUBJECTS Lower Limb	%	Upper Limb	%	Total	%
4-6 mos	10	4.3	2	0.9	12	5.2
6-12 mos	45	19.6	15	6.5	60	26.1
1-5 yrs	66	28.7	37	16.1	103	44.8
5-10 yrs	19	8.3	18	7.8	37	16.1
10+ yrs	7	3.0	11	4.8	18	7.8
Total	147	63.9	83	36.1	230	100.0

with disabilities had a prior history of respiratory or circulatory disease.

The results received were compared to the results in the control group (nondisabled) of 30 males, aged 20–40 years, who had no prior history of respiratory or circulatory disease. It should be noted that all subjects with lower limb disability performed wheelchair ergometry testing. In this connection, the control group was divided into two parts: group I, subjects who performed ergometry with their legs (15 men) and group II, subjects who performed ergometry with their arms (15 men).

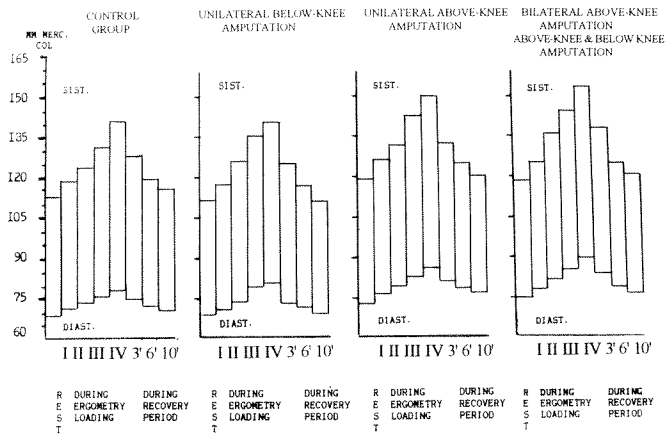

Figure 1.
The dynamics of the intra-arterial pressure in lower limb amputees during exercise training.

RESULTS AND DISCUSSION

Examination of the results of exercise training reveals that the most marked peculiarities in blood circulation can be observed in the subjects with lower limb amputation. The dynamics of intra-arterial pressure in wheelchair ergometry exercise testing shows practically the same response in both the subjects with BK amputation and in the nondisabled in control group II. The subjects with AK amputation demonstrated a trend of a more marked rise in intra-arterial pressure. The diastolic intra-arterial pressure in the subjects with AK amputation (the loading being submaximal) exceeds the corresponding values in control group II by 9.7 percent ($P<0.001$); the systolic inter-arterial pressure in control group II by 6.5 percent ($P<0.05$); and the average hemodynamic pressure in control group II by 9.2 percent ($P<0.01$). More marked difference in the above response is shown in the disabled-after-bilateral-amputation group (AK, AK+BK) and in the control group: the diastolic inter-arterial pressure response exceeds the corresponding values in control group II by 14.0 percent ($P<0.01$); average hemodynamic pressure value by 8.4 percent ($P<0.01$); and systolic inter-arterial pressure by 9.8 percent ($P< 0.01$) as seen in **Figure 1**.

Table 3 gives the dynamics of blood circulation responses to wheelchair ergometry exercise training.

A marked increase of heart rate in all groups with disabilities (regardless of the level of amputation) compared to control group II is demonstrated, the loading being submaximal, it amounts to 10.8 percent ($P<0.05$) in the subjects with BK amputation, 15.0 percent ($P<0.01$) in the subjects with AK amputation, and 16.9 percent ($P<0.01$) in the subjects with bilateral lower limb amputation.

Thus, a more marked inter-arterial pressure response (as well as a higher pulse) in subjects after maximal body mass loss, in cases where the recovery period was prolonged (compared to nondisabled), is estimated as a marked reaction of a hypertonic type that is considered as a decrease in dynamic capabilities of blood circulation.

Figure 2 gives the dynamics of heart rate, minute circulation volume, and stroke volume. The subjects with AK amputation and bilateral lower limb amputation demonstrated some regular decrease in minute circulation volume rise at the loading peak as well as a marked stroke volume decrease compared to the nondisabled. In all exercise training by the subjects with amputation in the above-mentioned group, the increase of minute stroke volume was solely at the expense of heart rate. In this connection, the examination of varying stroke indicator deserves more attention. The stroke indicator in the subjects with AK amputation was drastically lower than in the control group, the difference being 31.0 percent ($P<0.01$) and 26.7 percent ($P<0.001$) after the third exercise loading and submaximal loadings, respectively. The difference in the subjects with bilateral lower limb amputation was 46.1 percent ($P<0.001$) after submaximal exercise loading, which caused a depression of the "pumping" heart function in all groups of subjects with amputation. All of the above were markedly shown in subjects after maximal body

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Table 3.
Hemodynamic responses in subjects with lower limb amputation to wheelchair ergometer exercise testing (M ± m)

Indexes	Unit of Measure	Group	Rest	After 1st Exercise	P 4-5	After 2nd Exercise	P 4-7	Afte 3rd Exercise	P 4-9	After 4th Exercise	P 4-11	After 10min. Recovery	P 4-13
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Heart Rate	1 min.	Control group II	72.4±2.1	74.0±2.2		81.7±2.4	<0.02	103.7±4.0	<0.001	135.1±5.1	<0.001	86.2±3.1	<0.01
		Below-knee amp.	72.8±1.8	79.6±2.7		89.6±2.6	<0.001	118.5±3.8	<0.001	149.8±4.6	<0.001	84.8±2.2	<0.001
		Above-knee amp.	73.8±2.1	82.8±2.6	<0.02	95.3±2.7	<0.001	129.7±4.7	<0.001	155.4±3.3	<0.001	99.4±2.5	<0.001
		Bilat. above-knee amp.	79.2±2.1	89.0±2.3	<0.01	110.2±3.5	<0.001	141.4±4.6	<0.001	157.9±3.2	<0.001	104.3±2.8	<0.001
Stroke Volume (Systolic Volume)	ml	Control group II	88.9±5.1	94.8±7.2		114.0±7.3	<0.05	129.1±9.6	<0.01	152.2±10.9	<0.001	104.4±7.4	
		Below-knee amp.	77.9±3.7	85.5±4.3		94.3±4.3	<0.02	114.5±5.5	<0.001	108.4±6.5	<0.001	88.2±3.2	
		Above-knee amp.	69.0±4.2	79.5±6.5		86.6±5.7	<0.05	86.2±5.8	<0.05	72.6±6.0		75.0±6.2	
		Bilat. above-knee amp.	73.5±5.3	75.9±5.7		84.7±7.3		79.8±8.4		73.2±8.6		84.7±8.5	
End Diastolic Volume	ml	Control group II	157.4±9.9	163.9±11.4		190.5±10.2	<0.05	199.2±14.5	<0.05	218.3±18.0	<0.05	180.7±8.2	
		Below-knee amp.	135.7±7.2	141.4±8.9		161.0±8.5	<0.05	177.8±10.9	<0.01	154.3±11.8		155.4±8.3	
		Above-knee amp.	120.2±8.5	127.0±9.0		137.1±9.5		127.6±8.4		101.8±10.8		126.4±9.5	
		Bilat. above-knee amp.	118.2±8.8	123.0±10.4		127.5±11.5		124.8±12.8		100.4±12.6		135.6±12.4	
End Systolic Volume	ml	Control group II	69.0±2.7	67.1±6.3		66.2±6.5		65.3±6.4		60.4±7.3		81.6±4.5	
		Below-knee amp.	53.2±4.7	51.7±6.0		52.8±4.5		48.3±5.1		49.3±5.9		60.4±5.8	
		Above-knee amp.	47.8±4.5	49.1±6.1		44.5±5.9		39.9±5.8		28.8±4.8	<0.02	50.4±6.4	
		Bilat. above-knee amp.	42.8±5.9	46.8±7.6		40.8±7.9		37.5±8.6		27.2±7.8		51.9±9.5	
Minute Blood Circulation Volume	L/min.	Control group II	5.87±0.30	6.27±0.36		8.64±0.46	<0.01	11.82±0.62	<0.001	18.52±0.83	<0.001	8.33±0.45	<0.01
		Below-knee amp.	5.57±0.24	6.74±0.41	<0.05	8.27±0.48	<0.001	12.59±0.74	<0.001	15.53±0.93	<0.001	8.65±0.54	<0.01
		Above-knee amp.	5.20±0.30	6.52±0.32	<0.02	8.20±0.46	<0.01	10.81±0.57	<0.001	11.80±0.73	<0.001	6.98±0.35	<0.01
		Bilat. above-knee amp.	5.23±0.42	6.80±0.51	<0.05	8.73±0.62	<0.01	10.11±0.81	<0.01	10.95±0.90	<0.01	8.55±0.65	<0.01
Twice the product	Arbitrary	Control group II	80.9±3.1	87.4±3.4		101.3±4.4	<0.01	135.9±6.6	<0.001	189.7±11.3	<0.001	98.3±3.8	
		Below-knee amp.	80.8±2.1	91.2±3.2	<0.02	109.0±4.0	<0.001	158.2±5.9	<0.001	207.2±9.8	<0.001	95.6±2.7	<0.001
		Above-knee amp.	87.7±2.7	104.0±3.7	<0.01	125.5±3.9	<0.001	184.1±7.8	<0.001	230.8±5.9	<0.001	118.7±4.4	<0.001
		Bilat. above-knee amp.	92.2±2.3	111.6±3.7	<0.001	143.1±5.6	<0.001	202.9±7.0	<0.001	242.6±5.6	<0.001	123.1±4.0	<0.01

Amp. = Amputation Bilat. = Bilateral Min. = Minute

mass loss. The dynamics of stroke indicator are shown in **Figure 3.** The data obtained allow a definite conclusion about direct relationship between myocardium status and body mass reduction.

Examination of aortic (left) ventricle indicators' dynamics in subjects with high-level lower limb amputation revealed a qualitative distinction from that in control group II. An increased intensity of blood circulation in nondisabled during exercise training is accompanied by an increase of end diastolic volume of the aortic (left) ventricle (ED), an adequate diastolic filling, and some decrease of end systolic volume (ES), all of the above provided a rise in systolic output. Subjects with BK amputation showed an increase of EDV after the first, second, and third exercise training, while the decrease was observed after the submaximal exercise training, the difference in control group II was 29.4 percent ($P<0.05$). Subjects with AK amputation showed an increase of EDV after the first and second exercise

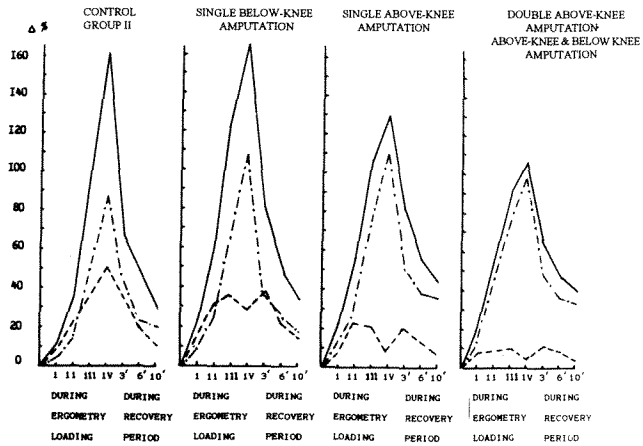

Figure 2.
The dynamics of heart rate, minute circulation volume, and stroke volume in lower limb amputees during exercise training. Designations: solid line = minute circulation volume; dot and dash line = heart rate; and, dash line = stroke volume.

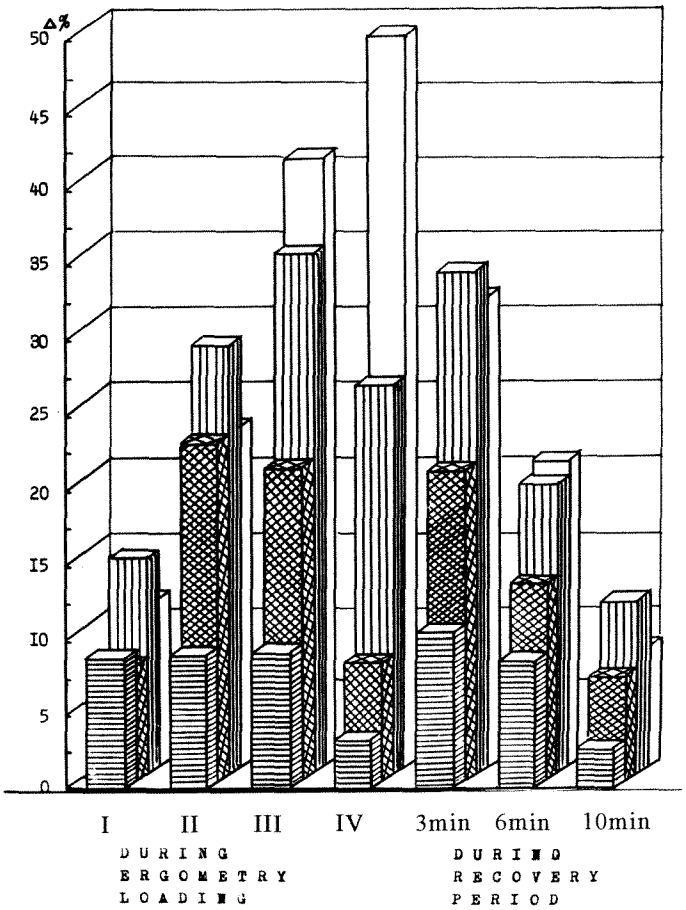

Figure 3.
The dynamics of stroke indicator in lower limb amputees during exercise training. Designations: solid bar = control group II; vertically lined bar = below-knee; hatched bar = above-knee; horizontally lined bar = double lower limb amputation.

training; however, this was less than in the nondisabled. The difference in control group II was 22.6 percent ($P<0.05$); 28.1 percent ($P<0.01$); 36.0 percent ($P<0.01$); and 53.4 percent ($P<0.001$) after the first, second, third, and submaximal exercise loading, respectively. A marked difference was shown after a recovery period. The difference in subjects with bilateral amputation was 25.0 percent ($P<0.05$); 33.1 percent ($P<0.01$); 37.4 percent ($P<0.01$); and 54.1 percent ($P<0.001$), respectively. Furthermore, a decrease of EDV was accompanied by a decrease of ESV. The difference in ESV between the subjects with AK amputation and control group II was 32.8 percent ($P<0.05$); 38.9 percent ($P<0.05$); and 52.4 percent ($P<0.01$) after the second, third, and submaximal exercise loadings, respectively. In the subjects with bilateral amputation, 38.4 percent ($P<0.05$); 42.6 percent ($P<0.05$); and 55.0 percent ($P<0.02$), respectively. The dynamics of EDV and ESV of the aortic (left) ventricle in the subjects with amputation compared to the nondisabled is shown in **Figure 4.**

Thus, cardiac function can adapt to a reduced venous inflow (when coupled with a distinct body mass reduction), vascular channel decrease, reduction in blood flow volume, and venous recurrence; all of the above appear as both EDV and ESV decrease at rest. The capability for an adequate increase in venous recurrence and diastolic filling of the aortic (left) ventricle ceases, which appears as

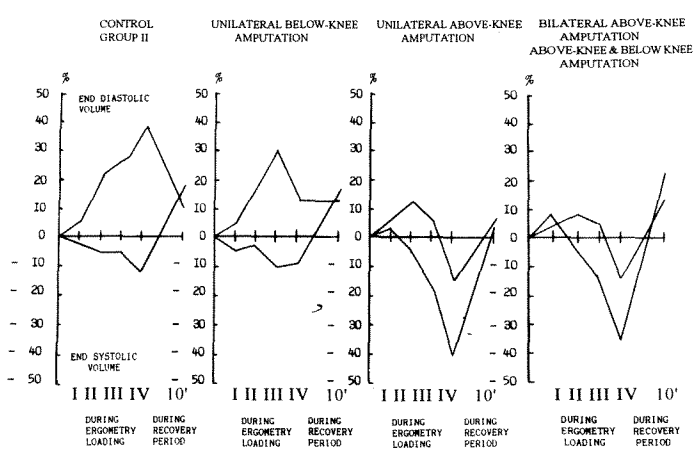

Figure 4.
The dynamics of end diastolic volume and end systolic volume of aortic (left) ventricle in lower limb amputees during exercise training.

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both EDV and ESV decrease and the lack of physiological increase of stroke volume.

An increased intensity of blood circulation in the nondisabled during exercise training was accompanied by a regular increase in indicators showing contractile function of myocardium: output fraction and the rate of regular shortening of myocardium fibers (Vcf), which achieve maximal values at submaximal exercise loading. The above variations show adequate increase in contractile function of myocardium. The highest change in output fraction was observed in the nondisabled subjects after the third exercise loading, while a decrease was observed after submaximal exercise loading. The subjects with a high level of amputation showed further regular decrease of output fraction as the intensity of blood circulation increased, a discrepancy (gap) between the responses in the subjects with amputation and the nondisabled grew. A similar picture was observed in Vcf examination. The dynamics of output fraction and Vcf showed a regular decrease in contractile properties of myocardium in the subjects with amputation, depending upon the amputation defect. The change of contractile function of myocardium in the subjects with amputation in exercise training influenced the cardiac indicator value which appears lower than in control group II. The above difference in the subjects with AK amputation or bilateral AK amputation was 36.3 percent ($P<0.001$) and 40.9 percent ($P<0.001$), respectively.

The reduced dynamics in blood circulation and reduced tolerance to exercise loading is considered to reduce working capacity. A direct relationship between working capacity and body mass loss was observed. The oxygen value of systole was revealed to be reduced at submaximal loading. However, maximal oxygen intake calculated in reference to reduced surface of the body was observed as remaining normal. The breaking of correlation interrelationships between working capacity indicators was revealed in the subjects with bilateral lower limb amputation, which differentiates this group from other groups. The interrelationship between PWC_{150} and MOI in the nondisabled in control group II is defined by the correlation factor $(R)=0.981$, between PWC_{170} and $MOI=0.962$. In the subjects with amputation, it was -0.010 and -0.393, respectively. Thus, it is believed that at a marked body mass loss the oxygen intake does not occur with a work capacity increase.

The reduction in respiratory capabilities in lower limb disabled (maximal body mass loss) was revealed at peak exercise loading alone, being demonstrated as a stabilized breathing capacity. The dynamics of breathing rate, breathing capacity, and minute respiratory volume are shown in **Figure 5.** As indicated, the performance of submaximal exercise loading in subjects with lower limb bilateral amputation was accompanied by a certain decline in breathing capacity, as well as a slight increase of minute respiratory volume (compared to the third loading). Thus, the increase of minute respiratory volume in submaximal exercise loading (compared to the third loading) was observed to be 46.6 percent ($P<0.001$), 30.3 percent ($P<0.001$), 21.6 percent ($P<0.001$), and 5.9 percent in the nondisabled, subjects with AK amputation, BK amputation, and bilateral amputation, respectively. Moreover, the slowing-down in the recovery processes after exercise training was revealed in the subjects with lower limb amputation. The respiratory indicators were observed to be completely normalized at 15 to 18 minutes into the recovery period.

The dynamic condition of the respiratory system is known to show a direct relationship to the blood circulation system, the latter system being an essential limiting factor in oxygen transport during muscular work. Cardiac capacity, in particular, is the main limiting factor, since cardiac output value is considered to be the main determinant value of

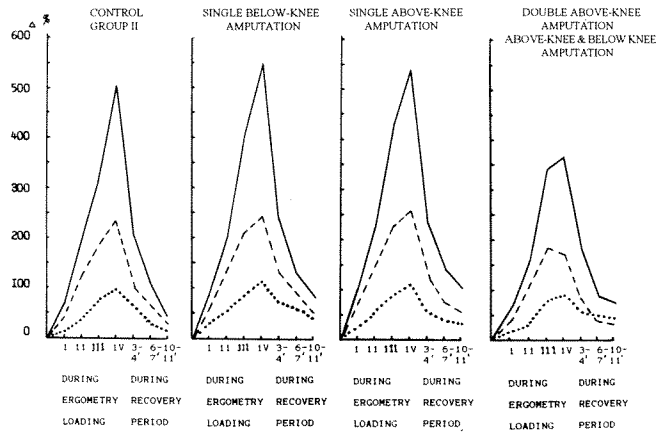

Figure 5.
The dynamics of breathing rate, breathing capacity, and minute respiratory volume in lower limb amputees during exercise training. Designations: solid line = minute respiratory volume; dashed line = breathing capacity; dotted line = breathing rate.

oxygen transport in the performance of exercise loading. Cardiac capacity can be considered as an integral indicator characterizing the transporting capacities of the cardiac and respiratory systems in relation to the presence of gases in blood (19). Homeostasis changes (changes in the central hemodynamics in subjects with amputation) influence the respiratory system condition. Body mass reduction, vascular channel reduction, blood flow volume reduction, reduction in contractile myocardium capacity, energy (and oxygen) demand reduction result in pulmonary ventilation and respiratory capacity decline.

Changes in blood circulation in subjects with upper limb amputation (shoulder level) are observed to be less. All of the subjects with upper limb amputation demonstrated adequate responses in intra-arterial pressure and volume values of hemodynamics, no essential changes being observed from corresponding values in control group I. No evidence of disturbances in contractile capacity of myocardium was observed in the subjects with upper limb amputation. Also, in the subjects with lower limb amputation decline in working capacity was revealed to show a direct relationship to amputation defect. Correlation relationships between working capacity's functions were not upset.

Changes in external respiration appeared to be most serious in the subjects with upper limb amputation. A decline in breathing capacity in the rest (and in other values characterizing respiratory function) was revealed. The breathing capacity was observed to be lower by 23.4 percent ($P<0.01$) and 30.1 percent ($P<0.001$) than in control group I, and in the subjects with amputation at shoulder level or bilateral amputation at shoulder level), respectively; the decline in breathing capacity influenced the minute respiratory volume value which was lower by 17.6 percent ($P<0.05$) and 21.5 percent ($P<0.02$), respectively, at a practically invariant breathing rate. Maximal ventilation was also observed to be reduced by 31.1 percent ($P<0.001$) and 29.0 percent ($P<0.01$) in subjects with amputation at shoulder level and in subjects with bilateral amputation at shoulder level, respectively. The relationship between the actual maximal ventilation and the proper value was 65.7 ± 5.1 percent and 72.1 ± 8.5 percent, respectively. Lung capacity was revealed to be lower by 24.4 percent ($P<0.001$) and 20.2 percent ($P<0.01$) in subjects with upper limb unilateral and bilateral amputation, respectively, compared to control group I. Reserve inhale volume was observed to be less by 22.6 percent ($P<0.01$) and 19.3 percent ($P<0.05$) in subjects with upper limb unilateral and bilateral amputation, respectively, while reserve exhale volume was less by 46.0 percent ($P<0.01$) and 52.5 percent ($P<0.01$), respectively, compared to control group I. A marked decline of expiratory flow rate also was observed. A decline of volume expiratory flow rate is thought to be mostly at the expense of initial portions of exhaled air.

No interrelationships were revealed between any indicator change and the extent of amputation defect (i.e., unilateral or bilateral upper limb amputation). The increase of breathing capacity was observed to be less marked in exercise training (compared to control group I); the capacity for adequate increase of maximal ventilation was lost, the latter being rather important. The above result in a decline in pulmonary ventilation rate and a decline in indicators of pulmonary capacity, as well as a slow-down in the recovery period. Changes in certain indicators of external respiration are given in **Table 4.** The dynamics of maximal ventilation are shown in **Figure 6.**

Anatomic, dynamic, and biomechanical disturbances and dystrophic processes (associated with the shoulder girdle and thorax) occur after upper limb amputation. Muscular system examination (by electromyography and reovasography methods) demonstrates atrophy occurring both in arm and shoulder muscles. The higher the level of upper limb amputation, the more the degenerative and dystrophic processes develop. A decline in blood filling in humerus muscles is observed (20,21).

After amputation at shoulder level (AE amputation) or after exarticulation of the shoulder girdle [shoulder disarticulation (SD amputation)], many of the muscles (i.e., pectoralis major, pectoralis minor, latissimus dorsi, and serratus anterior) lose their fixation points; all influence respiration.

Thus, the sum total of anatomic and biomechanical disturbances and dystrophic processes progressing as a result of amputation is responsible for the decline in thorax mobility as well as lack of mobility increase in exercise training. It is our opinion that decrease of dynamic capabilities of respiratory system and decrease of ventilation capacity enhance the risk of respiratory deficiency.

Table 4.
Responses of external respiration in subjects with upper limb amputation to ergometer exercise testing (M ± m)

Indexes	Unit of Meas.	Group	Rest	After 1st Exercise	P 4-5	After 2nd Exercise	P 4-7	After 3rd Exercise	P 4-9	After 4th Exercise	P 4-11	After 10min. Recovery	P 4-13
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Respiration Rate	1 min.	Control group I:	11.3±0.3	14.0±0.8	<0.02	15.2±1.1	<0.001	17.3±1.1	<0.001	22.1±1.7	<0.001	13.0±0.7	
		Unilat. amp. at shoulder lev.	12.9±0.5	16.7±0.7	<0.001	18.0±0.7	<0.001	20.3±0.7	<0.001	24.2±0.9	<0.001	16.8±0.8	<0.001
		Bilat. amp. at shoulder lev.	13.3±0.7	16.6±0.9	<0.02	18.3±0.9	<0.001	20.9±1.1	<0.001	24.3±1.2	<0.001	19.4±1.8	<0.01
Respiratory Min. Vol.	L/min.	Control group I:	9.88±0.49	16.49±1.33	<0.001	23.31±1.35	<0.001	33.51±1.49	<0.001	59.98±3.28	<0.001	13.73±0.76	<0.01
		Unilat. amp. at shoulder lev.	8.94±0.49	14.60±0.61	<0.001	22.91±0.81	<0.001	34.20±1.14	<0.001	53.30±2.13	<0.001	14.72±0.83	<0.001
		Bilat. amp. at shoulder lev.	8.09±0.55	13.91±1.00	<0.001	20.86±1.18	<0.001	31.06±1.85	<0.001	48.73±2.93	<0.001	15.35±1.32	<0.001
Max. Vent.	L/min.	Control group I:	120.9±7.4	133.2±8.2		143.6±7.8		146.5±7.6	<0.05	161.0±7.8	<0.01	148.8±8.7	<0.05
		Unilat. amp. at shoulder lev.	84.3±6.9	88.6±6.9		92.8±7.3		101.8±8.1		110.1±8.1	<0.05	94.7±7.9	
		Bilat. amp. at shoulder lev.	86.9±9.9	94.3±10.0		108.9±10.8		111.1±10.5		114.7±10.5		100.8±10.0	
Max. Vent. / Resp./Min./Vol.	%	Control group I:	1251.9±100.5	1036.8±102.9		815.0±96.0	<0.02	504.9±40.9	<0.001	315.8±34.8	<0.001	1158.6±108.4	
		Unilat. amp. at shoulder lev.	962.3±111.7	648.4±71.1	<0.05	432.3±39.5	<0.001	319.5±29.7	<0.001	208.6±14.1	<0.001	683.9±63.8	<0.05
		Bilat. amp. at shoulder lev.	1287.6±120.7	799.7±116.5	0.02	505.7±66.8	<0.001	334.9±39.4	<0.001	228.8±15.2	<0.001	763.6±85.8	<0.01
Max. Vent.- Resp./Min./Vol. / Max. Vent.	%	Control group I:	91.2±0.9	86.7±1.9		83.8±1.7	<0.01	77.4±1.6	<0.001	62.5±2.5	<0.001	89.3±1.2	
		Unilat. amp. at shoulder lev.	88.4±1.0	82.8±1.4	<0.01	73.8±1.9	<0.001	62.9±2.7	<0.001	51.2±2.6	<0.001	82.9±1.7	<0.02
		Bilat. amp. at shoulder lev.	90.3±1.7	82.2±2.4	<0.02	74.0±2.9	<0.001	63.2±3.0	<0.001	54.2±3.1	<0.001	83.4±1.7	<0.02

Amp. = Amputation Max. = Maximal Min. = Minute Vol. = Volume Bilat. = Bilateral Unilat. = Unilateral Vent. = Ventilation Resp. = Respiratory

Based on research carried out, the recommended balanced physical activities were calculated, as well as allowable conditioning exercises, for the subjects with amputation at various levels. The subjects with unilateral amputation (AK, BK, or at the level of shoulder) were determined as having average locomotory capabilities. The exercise training—the allowable level ranging from 40 to 60 percent of PMOI (i.e., 4.1–6.0 kcal/min) are recommended for the above group. The subjects with bilateral amputation (AK, BK, or at the level of shoulder) were determined as having reduced locomotory capabilities, and a fair exercise training was recommended—the allowable level ranging from 25 to 40 percent of PMOI (i.e., 2.6–4.0 kcal/min).

The maintenance of functional capabilities on a high level is known to be based upon the optimization of motor activity with an emphasis on aerobic exercise. It is shown (22) that the harmless value of exercise training is determined by MOI = 42 ml/kg/min or wheelchair ergometry index 2.8 W/kg/min in nondisabled males. As to wheelchair ergometry, the maximal allowable exercise loading was determined as being 1.7 W/kg/min and 1.0 W/kg/min in the subjects with unilateral or bilateral amputations, respectively.

The criteria of movement capabilities of persons with amputation were developed by the author based on the sum total of morphological and dynamic indicators, such as 1) changes in ECG and arterial pressure versus exercise loading; 2) heart rate at rest; 3) dystrophical myocardium changes; 4) maximal oxygen intake; and, 5) maximal pulmonary ventilation, etc. The implementation of these criteria

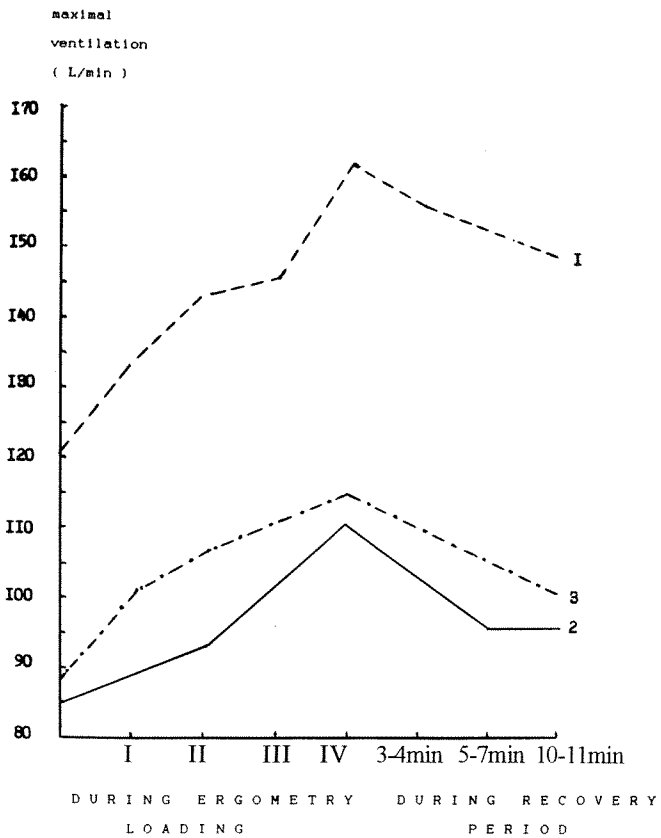

Figure 6.
The dynamics of maximal ventilation in subjects with upper limb ampation during exercise training. Designations: 1 = control group I; 2 = unilateral amp. at shoulder level; 3 = bilateral amp. at shoulder level.

provided the definition of an adequate set of conditioning exercises and the determination of a justified level of physical loadings.

The indicators in hemodynamics and external respiration (heart rate, diastolic and systolic arterial pressure, "double product," respiration rate) are defined for estimating physical capacity in persons with amputation. The values obtained in wheelchair ergometry testing in the subjects with unilateral amputation and corresponding to 50 percent of PMOI, as well as the values obtained in exercise testing in the subjects with bilateral upper or lower limb amputation and corresponding to 35 percent of PMOI, were taken by the author as the criteria. The above results are listed in **Table 5.** The indicators given are available for routine work, the correction of exercise loadings is provided; furthermore, the indicators can be used by the persons with disabilities for a self-checkup.

At the St. Petersburg Scientific Research Institute of Prosthetics, the necessary facilities are provided for physical rehabilitation of persons who sustained an amputation (i.e., swimming pool, gymnastic hall, and a hall equipped with exercise machines). A complete program for medical and social rehabilitation of persons with disabilities is provided as well.

It is our opinion that exercise equipment provides the most efficient rehabilitation. It provides physical fitness by 1) strengthening the upper limb

Table 5.
Allowable values for certain hemodynamic/external respiration responses to exercise training in subjects with various levels of amputation (M ± m).

Indexes		Unilat Amp Shoulder	Bilat Amp Shoulder	Unilat Amp BK	Unilat Amp AK	Bilat Amp AK & AK + BK
Heart rate	min^{-1}	115.1 ± 3.3	109.9 ± 2.4	118.5 ± 3.8	129.7 ± 4.7	110.2 ± 3.5
Diastolic BP	mmHg	79.1 ± 1.4	—	79.7 ± 1.1	83.2 ± 1.2	81.7 ± 1.7
Systolic BP	mmHg	134.3 ± 2.2	—	135.5 ± 2.1	143.2 ± 2.2	136.3 ± 1.7
Twice the product	arb	150.7 ± 5.9	—	158.2 ± 5.9	184.1 ± 7.7	143.1 ± 5.6
Resp rate	min^{-1}	20.9 ± 1.0	20.1 ± 1.2	21.9 ± 0.9	23.8 ± 1.1	17.9 ± 0.9

To our knowledge no suitable noninvasive method for blood pressure measurement is available.
Amp = amputation; Bilat = bilateral; Unilat = unilateral; AK = above knee; BK = below knee; BP = blood pressure; arb = arbitrary units; Resp = respiration.

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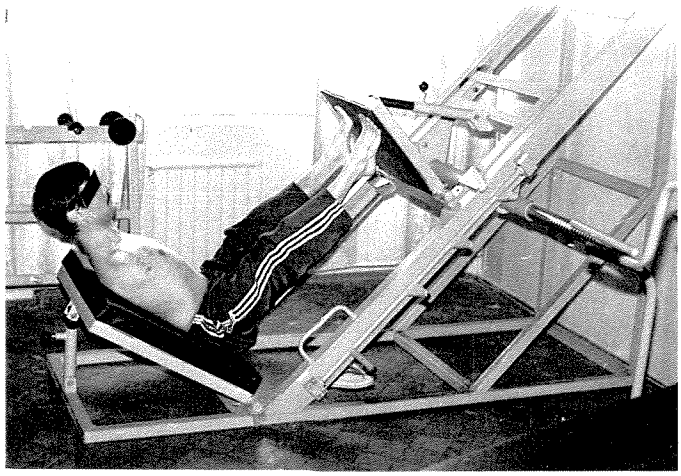
muscles, humeral girdle, and muscles of the back and muscles of the abdomen in persons with lower limb amputation, and 2) strengthening the lower limb muscles of the back and abdomen in those with upper limb amputation. Exercise training of the remaining muscle groups improves the condition of the cardiac and vascular systems. The total duration of exercise therapy ranged from 4 weeks to 2 months. Continuous medical supervision was provided. The examination of hemodynamics by means of echocardiography was carried out in 10 subjects with lower limb amputation during wheelchair ergometry exercise testing at the initial and final stages of training.

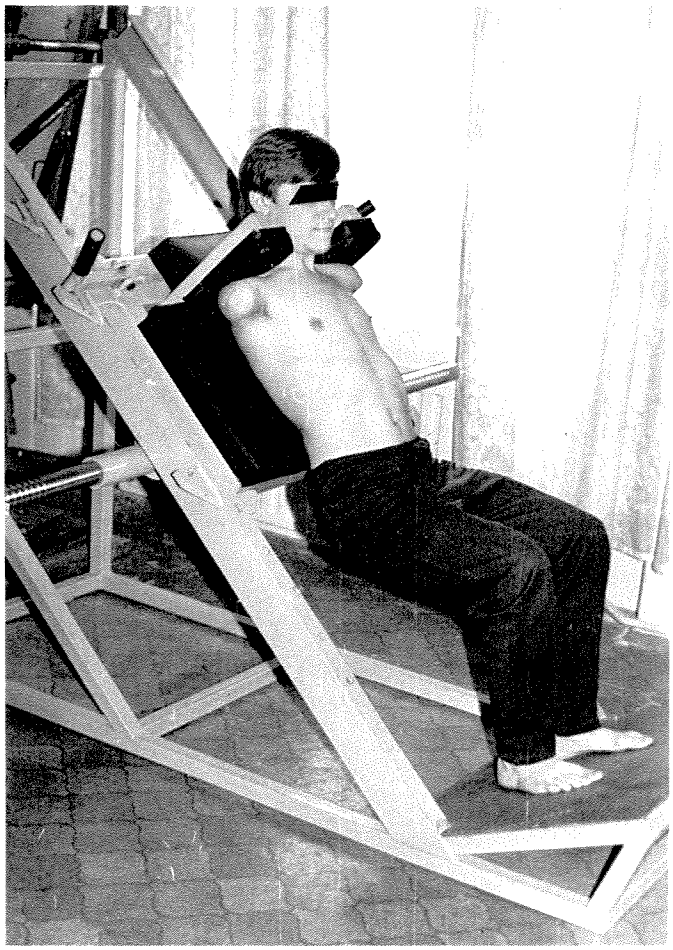
In the course of exercise training with the equipment, the average heart rate was 131.0 ± 2.8 sts/min; the average diastolic intra-arterial pressure was 76.5 ± 2.5 mm merc col; the average systolic pressure was 137.5 ± 3.1 mm merc col; "double product" was 182.0 ± 7.5 arbitrary units. The use of exercise training equipment by the subjects with upper limb/lower limb amputation is shown in **Figure 7.**

The examination of hemodynamics values, compared to the corresponding values for the initial period, obtained in submaximal wheelchair ergometer loading after a 2-month training period revealed the reduction of heart rate by 5.7 percent, the increase of stroke volume by 26.6 percent, and the increase of minute circulation volume by 27.7 percent. The rise of systolic output was at the expense of the rise of EDV, that is, diastolic volume of the aortic (left) ventricle. The rise of values characterizing contractile function in myocardium (output fraction by 11.9 percent, Vcf by 30.8 percent) was observed, which resulted in a rise in working capacity. Judging by the test PWC_{170}, working capacity increased by 5.4 percent and maximal oxygen intake by 6.2 percent.

Games are considered to be an efficient means for developing motor coordination capabilities. Subjects with amputation took part in volleyball, table tennis, badminton, running, and swimming. The sport was adapted depending on the level and the nature of amputation, age, and general physical fitness of each subject: the subjects with lower limb

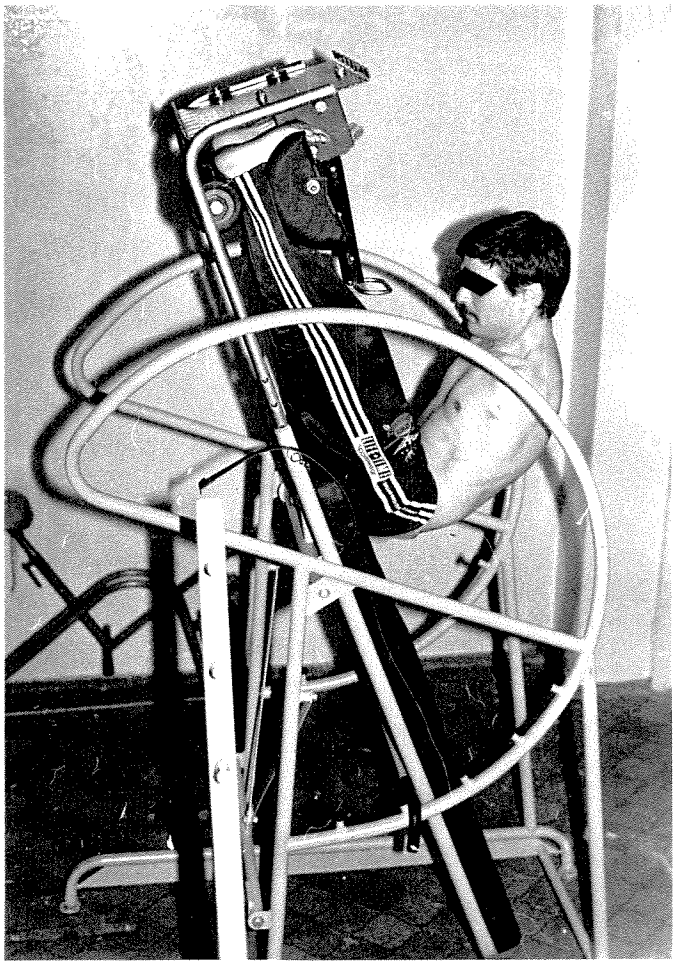


A



B

Figure 7.
Training at an exercise training machine. Subjects in A, B, and C have upper limb amputation; Subjects in D, E, and F have lower limb amputation.



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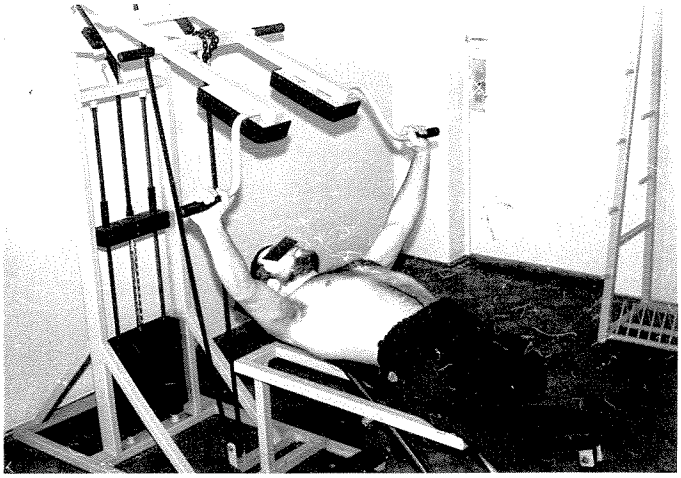

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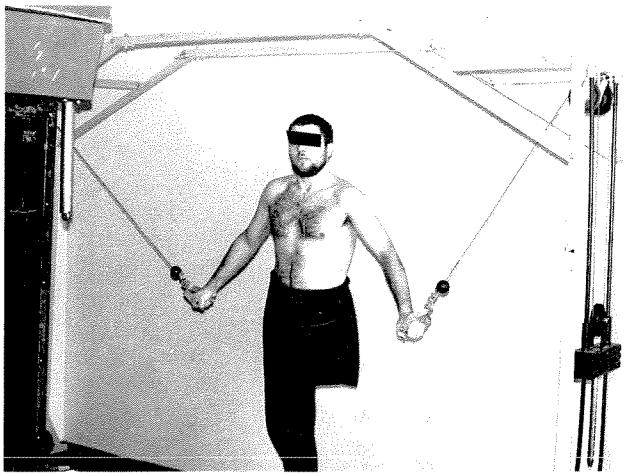
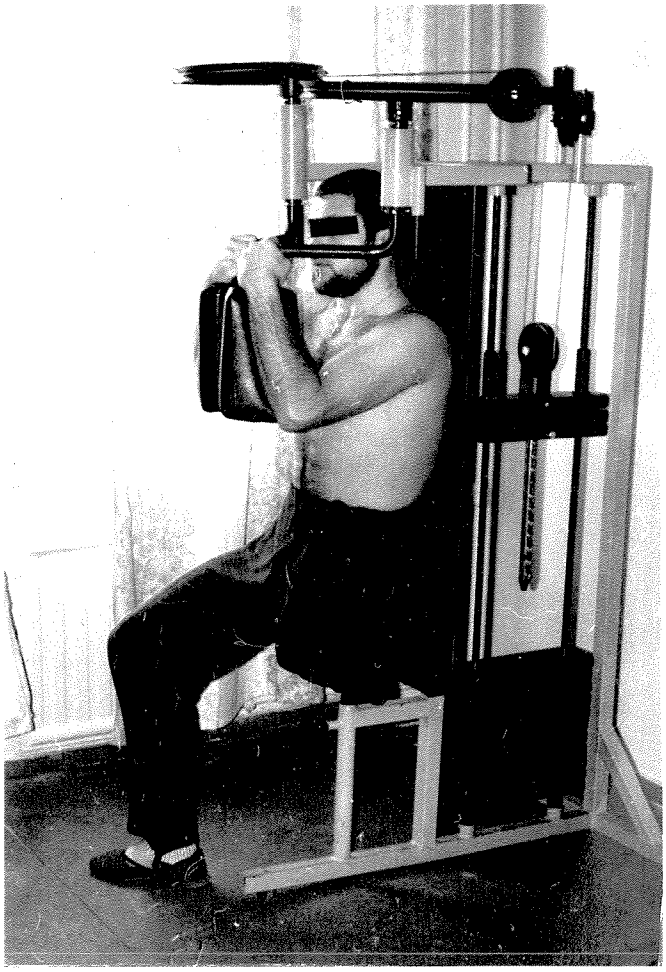


E



F

Figure 7. *(Continued).*

amputation preferred swimming, seated volleyball, and basketball; the subjects with upper limb amputation participated in table tennis, swimming, and running.

The physiological examinations demonstrated a decrease in tolerance for exercise training as a consequence of the decrease of dynamic capabilities of cardiac and respiratory systems, and the disturbances in contractile function of myocardium, as well as other consequences of amputation that limited motor capabilities in the subjects with amputation.

CONCLUSION

We can conclude that motor capabilities in persons with amputation depend not only on the level of amputation and the anatomical and functional condition of the residual limb, but to a large extent on the dynamic capabilities of their cardiac and respiratory systems. The results obtained allow us 1) to reveal the special feature of responses of cardiac and respiratory systems to balanced exercise training and 2) to find a valid approach to assess the criteria for the motor capabilities of persons with amputation, as well as the criteria for exercise-training endurance. Adequate tools of exercise training are considered to improve physical fitness and general working capacity in persons with amputation. The implementation in medical institutions of the sum total of amputee rehabilitation prepares adults with an amputation for their return to life in the community as able-bodied persons.

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