Acta of Bioengineering and Biomechanics
Vol. 15, No. 4, 2013

Original paper
DOI: 10.5277/abb130412

Evaluation of the effectiveness of training on a machine with a variable-cam

CZESŁAW URBANIK*, MICHAŁ STANISZEWSKI, ANDRZEJ MASTALERZ, MAGDALENA KARCZEWSKA, GRAŻYNA LUTOSŁAWSKA, DAGMARA IWAŃSKA, ANNA MADEJ, ELŻBIETA OSTROWSKA, LUCYNA GWAREK, JOANNA TKACZYK

Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education in Warsaw, Poland.

The aim of the study was to assess the effectiveness of the training of elbow flexors through the use of 2 machines, one of which was equipped with a disc plate of constant radius, the other one with a variable-cam having a radius adjustable to muscle strength. The experiment included 45 men divided into 3 equal groups: training group A (variable-cam), training group B (circle), and control group C. The training lasted for 8 weeks, 3 times a week. In order to control the effects, the values of peak torque and power of the flexor muscles of the elbow were isokinetically measured for the angular velocities of 30°/s and 60°/s. Also taken were anthropometric measurements of the arm and the creatine kinase (CK) activity in the blood plasma. As a result of the training, significant increases of biomechanical values were noted only in group A: power increased over 20%, the peak torque over 14%. After the training, significant increases of arm circumference in the relaxed position were noted in group A (17 mm), as well as in group B (11 mm). Also, some changes in CK activity were observed between Monday and Friday in a training week. On the basis of the experimental measurements, it may be ascertained that training elbow flexor muscles on a machine with a variable-cam is more efficient for increases in strength and power, as well as for some anthropometric parameters, than training on a machine with a disc plate.

Key words: *resistance training, elbow flexors, variable-cam, creatine kinase*

1. Introduction

Muscle strength is important not only in achieving maximum results in professional sports, but also in widely understood physical activities aimed at improving the bodies of people in various age groups and in physical rehabilitation whose purpose is to recover strength capacity to pre-injury levels [1], [2]. Strength, apart from velocity and endurance, is another fundamental and easily identifiable physical feature that can be influenced by means of proper training [3].

A muscle, or as a matter of fact, a sarcomere, being the basic contractible unit of a muscle cell, develops maximum velocity with the length, which is characterized by the highest number of active connections between myosin heads and actin active sites. When a muscle is lengthened beyond the rest length, the number of potential connections between myosin heads and actin decreases, thus the muscle strength decreases, too. When a muscle shortens to less than rest length, actin fibres start to overlap myosin and further even on themselves, which causes the opposite direction of action of force of some cross-bridges, so the resultant force of the muscle contraction decreases, too [4].

In human joints only rotary movements are possible, so muscle length depends on the muscle's angular position in the joint. That is why dependence between the strength and the length of a muscle translates into a dependence between strength and the angular position in a joint [1]. The value of peak torque as a function of the angular position is not constant. The results

* Corresponding author: Czesław Urbanik, Chair of Anatomy and Biomechanics, Józef Piłsudski University of Physical Education in Warsaw, ul. Marymoncka 34, 00-968 Warsaw, Poland. E-mail: czeslaw.urbanik@awf.edu.pl

Received: October 16th, 2012
Accepted for publication: April 25th, 2013

of many tests show that the values of peak torque for various muscle groups arrange along curves; the differences between the maximum and the minimum values can reach several dozen percent [1], [5]–[15].

Changes that take place in the body due to strength training result from 2 basic mechanisms. The first is an adaptation of the nervous system, that is, an improvement of stimulations of active muscle motor units induced by training. The second mechanism is hypertrophy: the enlargement of skeletal muscles. During the first weeks of training, strength increase depends on the first mechanism. Only after a month of training can an increase in the volume of muscle tissue be observed [16]–[18].

In training oriented to increase muscle mass, an efficient range of repetitions is 8–12, while the energy used by working muscles during such effort comes mainly from anaerobic glycolysis. The time of breaks between sets should be adjusted so that a person is able to complete the given number of repetitions and sets. Numerous authors have proven that while performing 10 repetitions maximum in a set (10 RM), one needs at least a 3-minute pause in order to perform another set with similar intensity [13], [19]–[22].

In strength or muscle mass training, it is essential to exercise with an optimally selected external load such as free weights and weight machines. The machines make up the basic gym equipment in fitness and sports clubs, and their function consists in transferring the external weight of cast iron plates through a cord with a system of pulleys to a lever moved by the person exercising. The use of round plates translates into the external moment of a fixed value, that is, there is a discrepancy between the constant external weight and the muscle strength abilities. With machines like this, optimal load for muscles only occurs within a short range of a joint movement, which means that actual strength training occurs only on a short line segment of the angular path. On such equipment, the relatively lowest external load occurs at the angular position in which muscles can achieve the highest strength values.

This problem was mentioned by Smith in 1982 [23]. He presented a graphic illustration of the course of forces and the arrangement of force moments for flexion of the elbow joint with a load of free weights as well as with a load transferred through a plate with a variable radius – a cam. He compared the obtained results with the values of the muscles torque as a function of the angle in the elbow joint. He thus indicated that the course of load variability was far more similar in an exercise using a cam than with free weights.

Taking into consideration the fact that movement in human joints can only be rotary, then apart from the strength value, also the arm on which it operates influences the values of muscle torques. By adjusting the radius of a plate, it is possible to adjust the external load [1]. On the basis of that assumption, Stone and O'Bryant [24] designed a cam with 2 different radii. Depending on the direction of the installation of the cam, the person exercising resisted on the bigger or smaller arm. According to the designers' intentions, the bigger arm was intended for people expecting a heavier load.

Some producers started to design weight machines with variable-cams, which were supposed to suit the muscle strength abilities depending on the angular position in the joint. Due to the lack of exact test results, the cams used had the biggest radii in the middle part and smaller radii for the extreme ranges of movement. In 1990, Johnson [25] applied cinematographic analysis to check the compatibility of cam shape (machine resistive torque – MRT) in 4 machines used in training various muscle groups, with the muscle strength abilities depending on angular position in the joint (human torque capability – HTC). He stated that the cam was better adjusted to the knee flexors. The cam shape was too flat for the knee and the elbow extensors, while the muscle strength ability peak for the elbow flexors did not overlap with the largest radius of the cam.

McMaster et al. [12] proposed versatile cam shapes for various muscle groups, e.g., an ascending cam should be applied in machines imitating a dead lift, chest press, or squats; a descending cam in those machines imitating a seated row or lat (latissimus muscle) pull-downs. A bell-shaped cam fits the flexion and extension in the elbow and the knee joints.

On the basis of the tests conducted under isokinetic conditions, Folland and Morris [8] determined the changes of the values of extensor muscles torques depending on the angular position in the knee joint. The values arrange along a curve the shape of which corresponds with strength abilities of extensors in the knee joint in the function of angle. Next, they examined 8 training machines with cams, which were supposed to adjust the external weight to muscles strength properties, according to intent of the producers of the machines. It turned out that none of the machines fulfilled these conditions.

It is quite possible that a long period of training on a poorly constructed cam, one that causes an uneven load during the entire range of movement, can influence the adaptive and functional changes in muscles in a negative way.

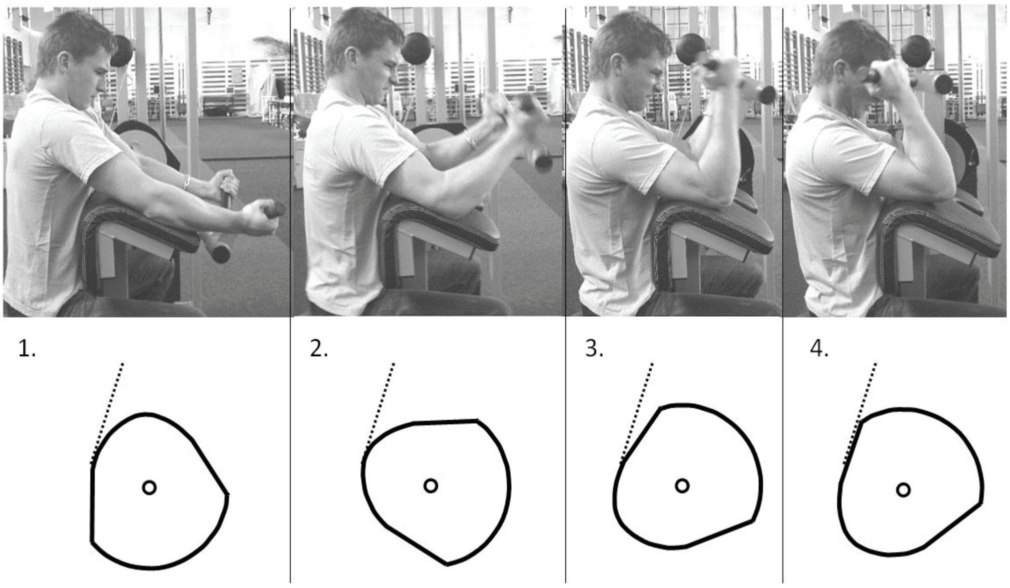

Fig. 1. Subsequent phases of the elbow joint flexion on a training machine, with the cam rotation scheme below

In order to assess the effectiveness of the use of cams in the training process, the shape of a cam was devised in a way to correspond with flexor muscle strength abilities as a function of changes of the angular position in the elbow joint (Fig. 1). The cam shape was developed on the basis of measurements of the force moments in the function of joint angle and adjusted by means of EMG examinations. The application of a properly constructed cam results in the values of external load in the entire range of movement being adjusted to muscle strength abilities. The proper muscle load during the whole movement should increase the effectiveness of strength or muscle mass training.

The dependence between the muscle strength and the angular position has been examined but has not been implemented in training practice. No studies have been conducted thus far with the objective of demonstrating whether a proportional muscle load is more efficient in a training process than training on a machine without an adjusted cam. For that reason, the aim of this research was to assess the effectiveness of elbow flexor training on 2 machines: one with a constant radius plate and the other one with a variable-cam adjusted to muscle strength abilities. The structure of the training was adapted to bodybuilding methods, which is the most popular way of developing strength and muscle mass.

On the basis of the theoretical speculations above, the following hypothesis may be proposed: Implementation of a cam that provides the most constant muscle activity in the whole range of movement during training will induce the highest increase in strength and muscle mass.

2. Materials and methods

2.1. Subjects

The subjects of the experiment were 45 not training students in their second year of studies at the University of Physical Education in Warsaw with an average age of 21 ± 1 years. The subjects were divided into 3 groups of 15 people: training group A (average body mass: 76.3 ± 8 kg; height: 180 ± 6 cm), training group B (average body mass: 79.3 ± 10 kg; height: 183 ± 7 cm), control group C (average body mass: 79.2 kg ± 10; height 183 ± 6 cm). All the individuals were familiar with the aim of the study and with the schedule of the tests, and they signed a written agreement for participation in the experiment. The consent for the study was granted by the Committee on Ethics of the University of Physical Education in Warsaw.

2.2. Training

Group A trained on a machine with a cam; group B – on a machine with a disc plate; group C participated only in the control measurements.

Training was carried out on a machine for training flexor muscles in the elbow joint made by MASTER-SPORT Poland (Fig. 1). Training lasted for 8 weeks with training sessions occurring 3 times a week (Monday, Wednesday, and Friday). A training unit consisted of 4 sets of 10 repetitions with 3-minute pauses. Each repetition, that is, a fluent flexion in the elbow joint (concentric contraction) and extension (eccentric contraction), took 4 seconds. Pace was kept with a beating metronome [13]. Before the exercise, the subjects performed an individual warm-up of the working muscles.

The load was individually selected for each subject to the nearest 5 kg. On the basis of preliminary studies, it was determined that the subjects were able to do 10 repetitions in 4 sets with the load at 50% to 60% of their maximum abilities. Three days before the start of the training, the maximum load for each individual was assessed on the basis of measurements. The primary condition of determination of the maximum lifted load was the ability to do 10 repetitions in a row (10 RM). The load value was systematically controlled and adjusted during the entire training period.

so the subjects exercising worked with a constantly changing load that was adjusted to their muscle strength abilities. For that reason, it is very difficult to clearly determine the load value in kilograms of the mass lifted.

In order to compare both efforts, the work (W) performed was counted as a function of the load (m·g) and the height (h) to which it was lifted. As the duration (time) of a repetition was known, the power (P) of the exercise was also calculated. The mass of the cast iron plates lifted constituted a direct and only variable determining the load value in a single training unit. Table 1 presents the values of the weight used and of the work and the power of one repetition with which a training cycle was started and ended for both groups. Due to the variable cam, the subjects from group A started the training with one plate (5 kg) more, on average. However, the average work and power values of the exercise were comparable in both groups (the differences between groups were statistically irrelevant). Similar dependences are indicated by load and work values during attempts with maximum weight; although the load value was higher in group A, the work performed was almost equal.

Table 1. The average ± SD initial (pre) and final (post) values of the external load used, of the work performed, and of the power of a single repetition (concentric and eccentric contractions) with a training weight (Training) and the values ± SD of the weight used and of the work with the maximum weight (Max)

Group		Training			Max	
		External load (kg) Av. ± SD	W (J) Av. ± SD	P (W) Av. ± SD	External load (kg) Av. ± SD	W (J) Av. ± SD
A	pre	33 ± 7.5	222 ± 50	55.2 ± 12.8	60 ± 13.4	404 ± 90
	post	46 ± 8.8	310 ± 60	77.2 ± 15.0	77 ± 11.1	524 ± 102
B	pre	27 ± 6.7	210 ± 52	52.4 ± 6.6	52 ± 12.8	410 ± 102
	post	36 ± 6.1	286 ± 48	71.2 ± 5.1	66 ± 8.5	516 ± 86

During the 8 weeks of the training, the subjects participated in 24 training units in which they performed 96 sets, that is, 960 repetitions. Each of the repetitions took the given 4 seconds, thus the muscle load in a set lasted 40 seconds, and in a training unit – 2.5 minutes. It should be emphasized that half that time represents concentric contractions; the other half, eccentric contractions of the elbow flexor muscles.

In the training machine for group B, a plate in the shape of a disc was applied as the element transferring the load of the cast iron weights on a lever moved by the person who was exercising. A disc has a constant radius, so the exercising subjects made an effort with a fixed external load determined by the mass of the weight used, the length of the plate radius, and the length of the lever arm. In group A, training was performed on a machine with a cam of a variable radius,

2.3. Measurement

Control measurements were taken before the start of the training, after its end, and again after a 3-week period of inactivity. Measurements of both the values of muscles torques and elbow flexor power under isokinetic conditions were done using the right arm on the Biodex 3 machine, with 3 repetitions for each 2 angular velocities given: 30°/s (0.52 rad/s) and 60°/s (1.05 rad/s). Calibration of the machine was performed according to the manufacturer's specifications before every testing session.

The circumference of the right and the left arm in the relaxed position (in the middle of the length of the arm) and in contracted position (at the widest place) was measured with a measuring tape precise to 1 mm. Thickness of the skinfold was measured on the front and the back part of the right and the left arms with a skinfold calliper (Holtain Skinfold Caliper) precise to 0.2 mm.

During 2 weeks of the training, measurements of creatine kinase (CK) activity in blood plasma were taken. Blood for analysis was collected from the earlobe on Monday mornings before exercise and on Friday after the training. Measurements of the enzyme activity were done the same day. CK activity was measured using the spectrophotometric method with the wavelength of 340 nm with use of ready kits by Alpha–Diagnostics (Poland). The measurements were performed at a temperature of 37 °C, and the enzyme activity was measured in (U/l).

2.4. Statistical analysis

In order to evaluate the changes of the values of the biomechanical parameters discussed in the successive control measurements and to determine the differences between the groups, multivariate analysis of variance (ANOVA) for repeated measurements was used. For the evaluation of the dependence between the separate results, the Duncan multiple range test was applied.

For the evaluation of the differences of the anthropometric parameter values before and after the training for each group, the Wilcoxon signed rank test was applied. The comparison of differences between the groups was performed with the Mann–Whitney test.

In order to evaluate the changes of CK activity and the differences between the groups, the non-parametric analysis of variance for dependent variables (the Friedman ANOVA) was applied, and a comparison of the results in the successive weeks was made with the use of the Wilcoxon non-parametric test. The normality of distribution was evaluated with the Shapiro–Wilk test. The comparison of the activity of CK and of the changes of activity in the successive weeks in groups A, B, and C was performed with the Kruskal–Wallis test and the Mann–Whitney test.

For all the tests the test significance at the level $p < .05$ was used. For the analysis of the test results, a statistical package by StatSoft, Inc. (2011) STATISTICA (data analysis software system), version 10, was used.

3. Results

The mass of the load lifted was gradually augmented during the entire cycle on the basis of observations and subjective evaluation of the subjects doing the exercising. The intent was to maintain the load value, thus enabling execution of the maximum 10 repetitions in a set. Throughout the training, a significant, almost equal average increase of load was noted in both groups (Fig. 2). After 8 weeks, the subjects training in group A performed sets with a load heavier by 40%; in group B, the load was 36% heavier than at the start. Beginning the sixth week, the lifted load values were significantly higher than at the beginning of the experiment.

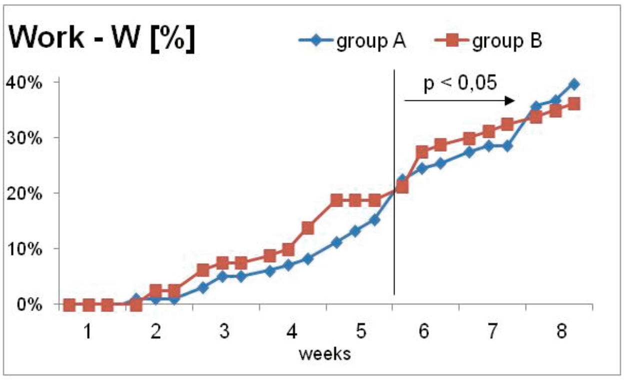

Fig. 2. Changes of performed work values over the training period on a machine with a cam (A) and with a disc plate (B)

Changes of the biomechanical parameters were evaluated on the basis of the isokinetic measurement of elbow flexor torques and power for the angular velocity corresponding with the velocity of flexion during the exercise on a training machine (60°/s = 1.05 rad/s) and the one half as slow (30°/s = 0.52 rad/s). The initial values of muscle torques were quite close not only in both training groups, but also in the control group, and equaled on average 59 ± 7 (Nm) for the measurement velocity 60°/s and 64 ± 10 (Nm) for 30°/s. The average power values before the training was 40 ± 7 (W) for velocity 60°/s and 24 ± 4 (W) for 30°/s.

For velocity at 60°/s, an increase of peak torque was observed by 13% in group A and by 6% in group B (Fig. 3). Although the increases were not statistically significant, they were worth noting, especially in contrast to the control group, in which the values decreased. The similar changes of average power could be observed. However, the increases in groups A and B were higher (20% and 10%, respectively), and additionally, this is statistically significant in group A in relation to the beginning of the training and to the results of the control group.

In comparison to the measurement velocity of 60°/s, for the measurement velocity of 30°/s, there was a greater increase of peak torque only in group A,

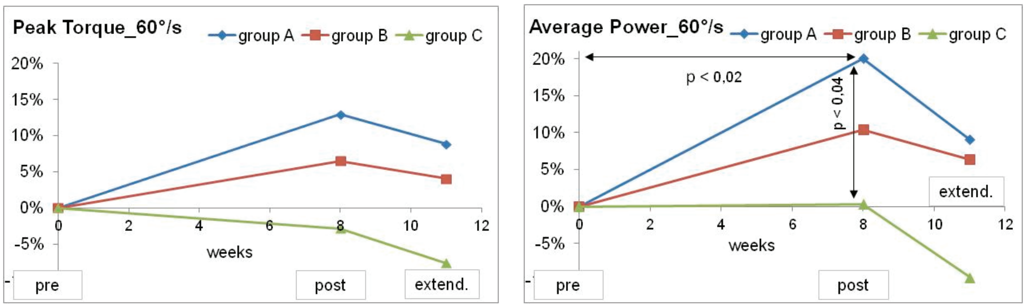

Fig. 3. Changes in the Peak Torque and Average Power values for measurement velocity of 60°/s, before (pre), after (post) and 3 weeks after completion (extended) of training on the machine with a variable-cam (group A), a disc plate of constant radius (group B), and the control group (group C)

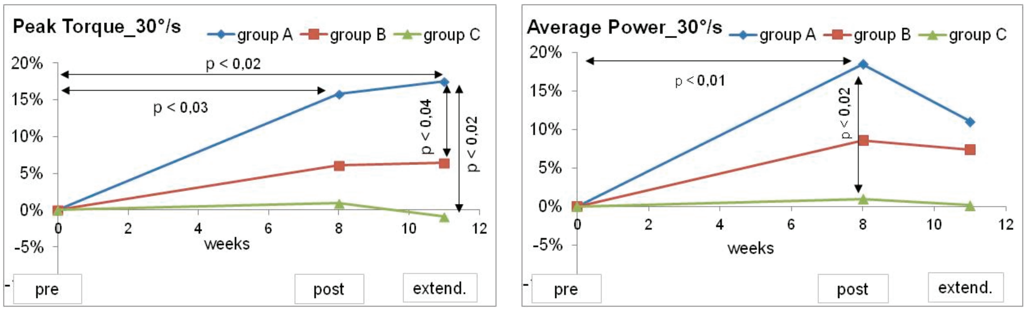

Fig. 4. Changes in the Peak Torque and Average Power values for measurement velocity of 30°/s, before (pre), after (post) and 3 weeks after completion (extended) of training on the machine with a variable-cam (group A), a disc plate of constant radius (group B), and the control group (group C)

reaching a level higher than the initial one by 16% after the training, and 17% after 3 weeks of rest (Fig. 4). The changes were statistically significant both in regard to the level before the training, as well as the measurements of groups B and C. The change of Average Power is very similar for both velocities.

Table 2 shows the circumference values of the right and left arms before and after the training. In both groups, there were significantly higher circumference values after training and a tendency for greater increase of values of the measurements performed in a relaxed position rather than in a contracted position. Arm circumferences grew by several millimeters more for people in group A than in group B, although the differences were not statistically significant. Only in group B can we see the difference in the measurements for the right and left side. The changes in the circumference values of the control group were not significant.

Table 3 presents skinfolds on the front side and back side of the right and left arms before and after training. The thickness of triceps skinfolds diminished significantly on an average of 1.4 mm (12%) in the subjects in group B and 1.7 mm (18%) in group A. The changes of biceps skinfolds were several times smaller and insignificant. There was a tendency for a greater reduction in skinfolds in group A than in group B. The changes in the control group (C) are within the range of measurement error.

There were very strong correlations between the right and left limbs in the values of anthropometric parameters, between the circumferences in relaxed position and in tension, and the skinfolds from the front side and back side of the arm.

An increase in CK activity in plasma, which is considered an indirect indicator of muscle damage, may illustrate the intensity of exercise. Increased CK activity may remain for a few days after exercise, which is why in the training process, the day-to-day increased activity of this enzyme can be observed in plasma. The measurement of CK activity for 2 weeks of training was to show whether loading a small muscle group with the training performed would cause this enzyme to occur in the blood, and whether it could be a tool to determine the differences between the types of applied loads.

The analysis showed no statistically significant differences between groups A and B, A and C, B and C for the mean values of CK activity and none for relationships Friday-Monday (in the first and second week) nor for differences Friday-Monday (in the first and second week) (Table 4). The reason for this is

Table 2. Values [cm] and changes in right and left arm circumferences in relaxed position (at rest) and contracted position (in tension). Mean data ± SD for groups before training (pre) and after (post). A – machine with a variable-cam, B – machine with a disc plate of constant radius, C – control group

Group	Right arm at rest		Right arm in tension		Left arm at rest		Left arm in tension	
	pre	post	pre	post	pre	post	pre	post
A	31.1 ± 2.7	32.8 ± 3.1	34.6 ± 3	35.8 ± 3	30.8 ± 3	32.5 ± 3.1	34.1 ± 3	35.2 ± 3.1
	[a,e] Δ = 1.7 cm (5,4%)		[d,e] Δ = 1.1 cm (3.3%)		[b,e] Δ = 1.6 cm (5.3%)		[b] Δ = 1.1 cm (3.1%)	
B	30.6 ± 2.6	31,7 ± 2.6	34.2 ± 2.8	35.2 ± 2.7	30.5 ± 2.7	31.5 ± 2.6	34.0 ± 2.6	34.7 ± 2.7
	[b] Δ = 1.1 cm (3.7%)		[b] Δ = 1.0 cm (3,0%)		[c] Δ = 0.9 cm (3.1%)		[d] Δ = 0.6 cm (1.9%)	
C	30.6 ± 2.6	31.0 ± 2.5	33.7 ± 2.6	33.9 ± 2.7	30.1 ± 2.7	30.6 ± 2.7	33.3 ± 2.6	33.5 ± 2.8
	Δ = 0.4 cm (1.4%)		Δ = 0.2 cm (0.7%)		Δ = 0.5 cm (1.9%)		Δ = 0.2 cm (0.5%)	

[a] – $p < .001$, [b] – $p < .002$, [c] – $p < .01$, [d] – $p < .05$, [e] – $p < .05$ between group A and C.

Table 3. Values (mm) and changes in skinfolds on the front (biceps) and back (triceps) side of the right and left arm. Mean data ± SD for groups before training (pre) and after (post). A – machine with a variable-cam, B – machine with a disc plate of constant radius, C – control group

Group	Right biceps		Right triceps		Left biceps		Left triceps	
	pre	post	pre	post	pre	post	pre	post
A	4.9 ± 1.1	4.5 ± 0.9	8.7 ± 2.4	7.0 ± 1.9	5.2 ± 1.2	4.7 ± 1.3	7.9 ± 2.2	6.3 ± 1.5
	Δ = –0.4 mm (–7%)		[a] Δ = –1.7 mm (–18%)		Δ = –0.4 mm (–8%)		[a] Δ = –1.6 mm (–18%)	
B	5.1 ± 2.2	4.9 ± 1.9	9.6 ± 3.9	8.2 ± 3.2	5.2 ± 2.1	4.9 ± 2.0	8.7 ± 2.8	7.2 ± 2.7
	Δ = –0.2 mm (–2.8%)		Δ = –1.4 mm (–12%)		Δ = –0.3 mm (–5.4%)		[b] Δ = –1.5 mm (–16%)	
C	4.9 ± 1.3	4.8 ± 1.3	8.2 ± 1.9	8.1 ± 1.9	5.0 ± 1.3	5.0 ± 1.3	7.7 ± 2.4	7.4 ± 2.2
	Δ = –0.1 mm (–0.9%)		Δ = –0.1 mm (–1%)		Δ = 0.0 mm (–0.0%)		Δ = –0.3 mm (–3%)	

[a] – $p < .002$, [b] – $p < .01$.

Table 4. Creatine kinase (CK) activity in plasma (mean ± SD) at the beginning (Monday) and end (Friday) of 2 weeks of training. A – machine with a variable-cam, B – machine with a disc plate of constant radius, C – control group

Group	CK (U/L)			
	Monday I	Friday I	Monday II	Friday II
A	474.3 ± 250.4	718.8 ± 540.4[a]	570.7 ± 464.5	923.7 ± 951.3[b]
B	376.7 ± 216.7	773.6 ± 802.8[c]	365.9 ± 198.1[d]	596.7 ± 356.6[e]
C	314.9 ± 160.7	516.5 ± 252.9[f]	417.4 ± 219.4	439.9 ± 253.7

[a] – $p < .05$ compared with Monday I, [d] – $p < .005$ compared with Friday I,
[b] – $p < .05$ compared with Monday II, [e] – $p < .002$ compared with Monday II,
[c] – $p < .02$ compared with Monday I, [f] – $p < .01$ compared with Monday I.

a significant variation of measurements and high values of standard deviation.

At the same time, there were significant differences in both training groups between subsequent days for each type of exercise. CK activity was significantly higher on Fridays than on Mondays, which may indicate the cumulative effects of training. Changes in CK activity were also found in the control group, but only in the first week of the study.

4. Discussion

Depending on the components of external load, strength training can affect such factors as increase in strength, power, hypertrophy, and strength endurance. By properly controlling load, a training process can be directed at the growth of a specific feature, but not in isolation from the alterations in other parameters [1], [16], [21]. Due to the adaptive properties of the body, it is the variation in the framework of training that is a prerequisite for the continued increase of effects [26], [27].

In our study, the load was set at a level to make it possible for the subjects to perform up to 10 repetitions per set (10 RM). Beginning the second week of training, the load was steadily increased, so that after 8 weeks of training the subjects exercised with the load increased by approximately 40% from the start initial week. Battoro studies [17] describe the training of 6 muscle groups, including the elbow flexors, which lasted for 6 weeks, 2 units a week, and this framework made the training load increase by only 10%.

The training load for individuals in group A amounted for 55% to 60% of maximum load; people in group B were within 59% to 65%. In similar training conducted by Garcia-Lopez [19], with a load of 60% of the maximum load, the people training were able to do 12 reps with a 1-minute break between sets, and 15 reps with a 4-minute break. Training load was calculated in relation to the maximum value in isometric contraction; hence, the greater number of possible repetitions in a set than presented in our study.

The framework of training for both research groups was the same. The analysis of the measurements showed that the size of training load (the value of work and power) was quite similar, and changes of these parameters during the entire cycle had a very similar course. Both types had the same training volume and intensity, and they differed only in the format in the bearing load on the training machine. Therefore, all intergroup differences in the post-exercise control effects will depend entirely on the type of applied load of working muscles: constant (disc plate) or variable (cam).

The applied training caused an increase in the peak torques and average power in the conditions measured isokinetically in both groups; however, the increase was significant only in the group training with the cam and twice as big as in the group training with the disc plate. In the training of a similar framework on a machine with a constant load of elbow flexors, Bottaro et al. [17] obtained increases in peak torques with an angular velocity of 60°/s at an average level of about 8%. These changes are closer to the measurements in group B (Δ = 6.5%) rather than in group A (Δ = 13%). In both groups, bigger changes were recorded for measurement of power rather than peak torques and for the smaller of 2 measurement velocities. The output of the peak torque values for velocity of 60°/s (on average 64 Nm) were higher than the results obtained by Bottaro et al. (on average 52 Nm) [16] and Beck et al. (on average 36 Nm) [27]. This may result from the research subjects that were students at a sports university. These students tend to be characterized by a high level of overall fitness.

In the experiment, visible changes in anthropometric parameters were observed. In both groups there was a significant increase in the circumference of the right and left arms, but it was bigger for the measurements performed in a relaxed position. In people training with the cam, the circumferences increased by approximately 1.7 cm (right limb) and 1.6 cm (left limb); in training with the disc plate, by 1.1 cm and 0.9 cm, respectively. The training also contributed favorably to changes in the thickness of skinfolds, although the differences were statistically significant only on the triceps. Despite the fact that the differences in the growth of arm circumference and thickness of the skinfolds were not statistically significant between the 2 training groups, the size, trend, and direction of these changes can be interpreted in favor of training with the cam, i.e., effort with variable muscle load.

An increase in arm circumference by 1.7 cm (5%) on average is a good result compared with studies by other authors. Kruszewski [29] obtained an increase in arm circumference of 1.9 cm (6%) in a professional athletics exercise lasting 3 months. After 5 weeks of effort on knee extensors on a training machine, Tesch et al. [15] obtained the values of quadriceps muscle volume that were 6% larger than before training. In an intense 2-week training, including 24 training units of 75 reps of bench barbell press with a load of 30% RM, Yasuda et al. [30] obtained an increase in triceps muscle thickness by 8%, and pectoralis major muscle by 16%.

Many authors have shown that upper limb muscles are less responsive to training load than lower limb muscles. With the same schedule, the effects of changes in strength and hypertrophy of elbow flexors appear after a long period of training and have a smaller increase than, for example, knee rectifiers [17], [28], [31], [32].

While an intensive effort, the level of muscle load is often assessed on the basis of enzymes secreted into the blood. The present experiment aimed at assessing CK activity in plasma, since this is an enzyme that is released when muscle cell damage is caused by exercise, and it then accumulates in the blood. The training schedule made in the study was a strong enough stimulus for elbow flexors that on Fridays at the end of the training week, CK activity in the plasma was significantly higher than on Mondays before the exercise began. The correlation occurred between 2 training groups, but there were no significant differences in values or changes between the groups.

It is sometimes thought that bigger muscle damage and associated higher CK activity in plasma occur after eccentric exercise [33]. Also, the range of muscle work may affect the activity of this enzyme. Nosaka et al. [34] demonstrated that after the eccentric work of elbow flexors, the greater difference in CK activity was observed for people training in the range of 100° to 180° rather than 50° to 130°. A significant increase in CK activity after one day of intense effort was noted by Philippou et al. [14]. The elbow flexors also worked for a larger angle in the joint, but in isometric conditions. Our own studies as well as those of others point to a large interindividual variability in the CK response to the effort performed [14], [33], [34].

Despite the lack of statistically significant differences between the groups, the trend and size of changes in biomechanical and anthropometric parameters indicate the favorable post-exercise changes among the people training on the machine with a specially constructed variable-cam. It is in biochemical analysis alone that these differences are not observable. It is worth noting that these 2 training groups differed only in the type of muscle load: variable with a cam, or fixed with a disc plate.

The experiment showed that the proposed framework for the training of elbow flexors is effective at increasing strength and power and has a positive influence on the growth of the working muscles. The programmed training intensity of relatively small muscle group was so large that it left an effect in the blood in the form of elevated CK activity.

Based on the results of this study, it can be concluded that training elbow flexors on a machine with a variable-cam is more effective at increasing strength and power and selected anthropometric parameters than training on a machine with a disc plate.

Using specially constructed variable cam in a training machine allows the external load to be adjusted to the possibility of muscle strength throughout the whole range of motion in the joint, which is important for efficiency, comfort, and safety of the exercises in sport, fitness and rehabilitation. In this arrangement, the muscles work in alignment with their biomechanical properties and thus are not vulnerable to adverse changes in their structure.

In designing exercise equipment, producers should take into account the characteristics of muscles, which will lead to more effective training. Similar studies will be repeated for training done with a different framework and for other muscle groups.

Acknowledgment

This study was supported by the grant from the Polish Ministry of Science and Higher Education as a Statutory Activity of the University of Physical Education in Warsaw (grant No. Ds-154).

References

[1] BISCARINI A., *Dynamic Effects of Muscle Moment Arm Variation and Heavy External Loads on Hinge Joints*, J. Appl. Biomech., 2003, Vol. 19, 223–238.

[2] CZAMARA A., KRZEMIŃSKA A., SZUBA Ł., *The influence of exercises under isokinetic conditions on heart rate in males aged between 40 and 51*, Acta Bioeng. Biomech., 2011, Vol. 13(3), 95–104.

[3] ZACIORSKI W., *Kształcenie cech motorycznych sportowca*, Sport i Turystyka, Warszawa, 1070.

[4] JASKÓLSKI A. (ed.), *Podstawy fizjologii wysiłku fizycznego*, Wydawnictwo AWF we Wrocławiu, 2002.

[5] BOBER T., HAY J.G., *Topografia siły mięśni kończyn człowieka*, WF i Sport, 1990, Vol. 3, 3–21.

[6] BOBER T., HAY J.G., *Dobór pozycji kątowych do pomiaru maksymalnych momentów sił mięśni w stawach kończyn człowieka*, Zeszyty Naukowe AWF Wrocław, 1991, Vol. 53, 5–15.

[7] BOBER T., PIETRASZEWSKI B., *Strength of muscle groups in swimmers*, Biology of Sport, 1996, Vol. 13(2), 155–164.

[8] FOLLAND J., MORRIS B., *Variable-cam resistance training machines: Do they match the angle – torque relationship in humans*? J. Sport Sci., 2008, Vol. 26(2), 163–169.

[9] KRAMER J., VAZ M., HAKANSSON D., *Effect of activation force on knee extensor torques*, Med. Sci. Sports Exer., 1991, Vol. 23(2), 231–236.

[10] KULIG K., ANDREWS J.G., HAY J.G., *Human strength curves*, Exp. Sport Sci. Rev., 1984, Vol. 12, 417–466.

[11] MASTALERZ A., URBANIK C., *Effect of isometric muscle precontraction in the isokinetic motions*, Acta Bioeng. Biomech., 2003, Vol. 5(s1), 329–334.

[12] MCMASTER T., CRONIN J., MCGUIGAN M., *Form of variable resistance training*, Strength & Conditioning Journal, 2009, Vol. 31-Issue 1, 50–64.

[13] OLIVEIRA L.F., MATTA T.T., ALVES D.S., GARCIA M.A.C., VIEIRA T.M.M., *Effect of the shoulder position on the biceps brachii EMG in different dumbbell curls*, J. Sports Science and Medicine, 2009, 8, 24–29.

[14] PHILIPPOU A., MARIDAKI M., BOGDANIS G.C., *Angle-specific impairment of elbow flexors strength after isometric exercise at long muscle length*, Journal of Sports Sciences, 2003, 21, 859–865.

[15] TESCH P.A., EKBERG A., LINDQUIST D.M., TRIESCHMANN J.T., *Muscle hypertrophy following 5-week resistance training using a non-gravity-dependent exercise system*, Acta Physiol. Scand. 2004, 180, 89–98.

[16] AHTIAINEN J.P., PAKARINEN A., ALLEN M., KRAEMER W.J., HAKKINEN K., *Short vs. long rest period between the sets in hypertrophic resistance training: influence on muscle strength, size, and hormonal adaptations in trained men*, Joumal of Strength and Conditioning Research, 2005, 19(3), 572–582.

[17] BOTTARO M., VELOSO J., FREITAS DE SALLES B., SIMAO R., CELES R., BROWN L.E., *Early phase adaptations of single vs. multiple sets of strength training on upper and lower body strength gains*, Isokinetics and Exercise Science 2009, 17, 207–212.

[18] MASTALERZ A., WOŹNIAK A., URBANIK C., LUTOSŁAWSKA G., *Contralateral effects after power training of isolated muscles in women*, Acta Bioeng. Biomech., 2010, Vol. 12(2), 65–71.

[19] GARCIA-LOPEZ D., DE PAZ J.A., MONEO E., JIMENEZ-JIMENEZ R., BRESCIANI G., IZQUIERDO M., *Effects of short vs. long rest period between sets on elbow-flexor muscular endurance during resistance training to failure*, J. Strength Cond. Res., 2007, Vol. 21(4), 1320–1324.

[20] KRAEMER W.J., *A series of studies: The physiological basis for strength training in American football; Fact over philosophy*, J. Strength. Cond. Res., 1997, Vol. 11, 131–142.

[21] MIRANDA H., FLECK S.J., SIMAO R., BARRETO A.C., DANTAS E.H.M., NOVAES J., *Effect of two different rest period lengths on the number of repetitions performed during*

resistance training, J. Strength Cond. Res., 2007, Vol. 21(4), 1032–1036.
[22] RICHMOND S.R., GODARD M.P., *The effect of varied rest periods between sets to failure using the bench press in recreationally trained man*, J. Strength Cond. Res., 2004, Vol. 18(4), 846–849.
[23] SMITH F., *Dynamic variable resistance and the universal system*, Nat. Strength Cond., Assoc. J., August–September, 1982, 14–19.
[24] STONE M., O'BRYANT H., *Weight Training: A Scientific Approach*, (2nd ed.). Burgess International, 1987.
[25] JOHNSON J.H., COLODNY S., JACKSON D., *Human torque capability versus machine resistive torque for four eagle resistance machines*, J. Appl. Sport Sci. Res., 1990, Vol. 4, 83–87.
[26] BAKER D.G., NEWTON R.U., *Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes*, J. Strength Cond. Res., 2006, Vol. 20(3), 541–546.
[27] TRZASKOMA Z., TRZASKOMA Ł., *Kompleksowe zwiększanie siły mięśniowej sportowców*, COS W-wa, 2001.
[28] BECK T., HOUSH T.J., JOHNSON G.O., WEIR J.P., CRAMER J.T., COBURN J.W., MALEK M., MIELKE M., *Effect of two days of isokinetic training on strength and electromyographic amplitude in the agonist and antagonist muscles*, J. Strength Cond. Res., 2007, Vol. 21(3), 757–762.
[29] KRUSZEWSKI M., *Efektywność metod rozwijania siły mięśniowej i suplementacji żywieniowej w aspekcie zmian potencjału ruchowego i składu ciała ćwiczących*, Studia i Monografie AWF Warszawa, 2008.
[30] YASUDA T., FUJITA S., OGASAWARA R., SATO Y., ABE T., *Effects of low-intensity bench press training with restricted arm muscle blood flow on chest muscle hypertrophy: a pilot study*, Clin. Physiol. Funct. Imaging., 2010, Vol. 30, 338–343.
[31] RONNESTAD B.R., EGELAND W., KVAMME N.H., REFSNES P.E., KADI F., RAASTAD T., *Dissimilar effects of one-and three-set strength training on strength and muscle mass gains in upper and lower body in untrained subjects*, J. Strength Cond. Res., 2007, Vol. 21(1), 157–163.
[32] TRAYLOR D.A., HOUSH T.J., CAMIC C.L., ZUNIGA J.M., BERGSTROM H.C., JOHNSON G.O., SCHMIDT R.J., LEWIS R.W., *The effects of short-term isokinetic resistance training on isometric and concentric torque of the forearm flexors in females*, J. Exerc. Physiol., 2012, Vol. 15(1), 110–115.
[33] NOSAKA K., CLARKSON P.M., *Variability in serum creatine kinase response after eccentric exercise of elbow flexors*, Int. J. Sport Med., 1996, Vol. 17, 120–127.
[34] NOSAKA K., SAKAMOTO K., *Effect of elbow joint angle on the magnitude of muscle damage to the elbow flexors*, Med. Sci. Sports Exerc., 2001, Vol. 33(1), 22–29.