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Validity of Mechanical Power Output Measurement at Bench Press Exercise

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In sport training and rehabilitation practice, it is usual to use methods of mechanical muscle power output measurement, which are based mainly on indirect force measurement. The aim of this study was to verify the validity of indirect measurement for mechanical muscle power output with bench press exercise. As a criterion of validity, we selected a combination of kinematic and dynamic analyses. Ten men participated in this study. Average age of tested subjects was 28.0 ± 3.4 years. At mechanical power output measurement, these subjects lifted at maximum possible speed loads of 18, 26.5, 39.2 and 47.7 kg. Validity of mechanical power output measurement by means of a method using indirect force measurement was estimated using Spearmen´s Correlation Coefficient. Factual significance of differences in average values of power output, force and velocity, measured by a method using indirect force measurement, in comparison to the selected criterion, was evaluated by means of effect of size. Power output measurement method using indirect force measurement showed lower values of force in relation to the criterion in the whole scope of selected loads. Velocity values in the whole scope of selected loads did not show any significant difference between the criterion and the verified method. The mechanical muscle power output measured by the method using indirect force measurement is lower in relation to the criterion, especially in the low scope of loads, where also validity rate was low (R = 0.5)..

Key words: bench press, fitrodyne premium, kinematic analysis, dynamic analysis

Introduction

The mechanical power output (P) is, in many sports, the most important element of sport performance (Kraemer and Newton, 2000). Value of P is in the course of performed motion given by the product of velocity (v) of moving body elements with load, and exerted force (F) induced by muscle activity. With force training of some athletes, arise a need to achieve maximum mechanical power output (P_m) as a supraliminal stimulus. A trainer needs to know the P_m value to be able to control efficiently a training regimen for each athlete. Force training is also an efficient therapy against muscle loss due to increasing age, known as sarcopenia, and also against muscular asthenopia, caused by inactivity as a result of disease (Niewiadomski, Laskowska, Gasiorowska, Gybulski, Strasz and Langfort, 2008). Due to the progress in development of measuring instruments used in biomechanics, it is now possible to estimate the mechanical muscle power output right in a training practice at force training, even at sport performances. Single methods of the mechanical power output measurement used at various exercises, need not be valid, though. This study is focused on bench press exercise.

There are three basic ways how to measure mechanical power output:

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1. methods using direct force measurement (forward dynamics approach - FD)
2. methods using indirect force measurement (inverse dynamics approach - ID)
3. combination of kinematic and dynamic methods

FD methods have an advantage over direct measurement of force, but vertical velocity at the center of gravity of the body and load is estimated from the following equation (Caldwell, Robertson & Whittlesey, 2004):

$$\boldsymbol{v}_{final} = \frac{\int_{t_{initial}}^{t_{final}} (\boldsymbol{F}_z - \boldsymbol{F}_G)dt}{m} + \boldsymbol{v}_{initial} \quad [1]$$

where $t_{initial}$ is the starting time and t_{final} is the terminal time of the motion, F_G is the gravity force, F_z is a force affecting the course of motion on the pad vertically (F_z is obtained by means of a force plate), m is the mass of a tested person with load, and $v_{initial}$ is the center of gravity velocity in the vertical direction. A key requirement for this analysis is zero velocity at the start of data collection. In other words, when we start our measurements, a dumbbell and a tested person must be quiescent. (Hori et al., 2006). If all the body elements of a tested person participating in the performed motion do not move in parallel with the dumbbell, we would obtain an erroneous calculation for the center of gravity velocity (dumbbell + load). In practice, weight of the system (body + load) is recorded before measurement, immediately on a force plate. However, in the following measurement, some body elements do not move at all, therefore a misinterpretation of the center of gravity occurs. Weight in this equation [1] is defined just for moving objects. Another limitation of this method is that a tested person must be independent of a force plate and any part of the body or dumbbell must not be in contact with any other object or with the floor. FD method is not recommended, for example, for power output measurement in exercises where a dumbbell is at the beginning of the exercise on the floor. This is because the system (body + dumbbell) must not be changed because of correctness of the center of gravity velocity calculation, and consequently power output calculation. At the beginning of this exercise a force plate measured only the progressively increasing weight of a tested person. As the tested person starts to lift a dumbbell, value m changes (mass system is not constant), and consequently the velocity calculation contains an error (Hori et al., 2006).

As can be seen from the name, ID method measures force F indirectly, for example by FitroDyne Premium (FDP) equipment, by means of directly measured load velocity v, load mass m and time t:

$$\boldsymbol{F} = m(\frac{d\boldsymbol{v}}{dt} - \boldsymbol{g}),$$

where g is the gravitational acceleration [2]

It is necessary to realize, that v, g and F are vectors, therefore, in vertical direction we use (+) for acting upwards and (–) for acting downwards. ID method presumes that a trajectory of a system (body + load) is equivalent to a dumbbell trajectory (Dugan, Doyle, Humphries, Hasson & Newton, 2004). This fact limits the ID method, because, for example, even in the knee-bend exercise--rise with countermotion (CMS)--or in the bench press (BP), limbs do not move in synchronization with the dumbbell. This fact generates inaccuracy in the power output measurement by the ID method. Another inaccuracy is caused by the fact that we do not know the exact weight of moving body elements with load over time. Because we cannot measure the center of gravity velocity directly, we estimate it by means of dumbbell velocity. Therefore, to a certain extent, the ID method distorts both values, power output F and center of gravity velocity v of a system (body + load) with mass m. Another limitation of the mechanical muscle power output measurement by the ID method (on FitroDyne Premia FDP) is the exact determination of motion velocity only in the vertical direction; hence, it is not very suitable to use FDP for exercises containing horizontal motions. Therefore, when using the ID method, it is crucial to estimate the actual weight of the moving load (body + external load) and to reach maximum possible correspondence in measuring the center of gravity velocity in the trajectory of a system (body + external load). Horri et al. (2006) presents that in such exercises as bench press, it is possible to disregard weight of the upper limbs in motion. In the situation where we measure, so-called, external output (i.e., output force (???) applied on an object), it is possible to execute this method with precision. For example, in training weight-lifters, their body often moves in the opposite direction to the dumbbell; therefore it is more convenient to use the ID method than the FD method. Both methods have their positives and negatives. The ID method advantage is a very fast interpretation, and possibility, to work with FDP in

the natural training environment of the athlete (Jennings, Viljoen, Durant & Lambert, 2005). Both in practice and in scientific research, equipment similar to FitroDyne Premium is used: Linear position Transducer or Plyometric Power System® (Falvo et al., 2005).

Cormie et al. (2007a) recommended a combination of kinematic and dynamic methods as valid mechanical muscle power output measurement. Force is measured on a force plate, and dumbbell motion is measured by FitroDyne Premia (or similar equipment). Consequently, the mechanical power output P is calculated simply as a product of force F and velocity v. Data from both devices, which measure force and velocity, are collected simultaneously. When using this method, a quiescent beginning and weight measurements of unmoving body elements are not necessary. The presumption of correlation between the trajectory of body mass and external load center of gravity, and the dumbbell trajectory is still valid, but usually it is not completely accomplished. An advantage of this method is a more accurate estimation of the center of gravity velocity in comparison with the FD method, and a more accurate force measurement in comparison with the ID method (Horri et al., 2006). However, a combined method is also limited. It cannot be used in such cases when a person's body moves in a different direction from the dumbbell, as characteristically seen in weight lifting. In such a case, it is not possible to multiple pressure force affecting on a force pad and a dumbbell motion velocity, which have numerous directions.

Surely we could debate the criterion of validity for mechanical muscle power output measurement. In light of logical reasoning, in the aforementioned paragraphs, we consider a combined method of mechanical muscle power output measurement as the most accurate protocol.

The aim of this study was to verify the validity of mechanical muscle power output measurement in bench press exercise, which measures force indirectly. As a valid criterion of mechanical power output measurement, we selected a method combining kinematic and dynamic analyses.

Method

Our research was conducted from the end of September through the end of December 2007, in Laboratory of Biomechanics at Massachusetts University Amherst.

Test Group

This study was performed on 10 men. The average age of tested subjects was (28.0 ± 3.4) years in the range of 21 to 31 years. The average height was 1.78 ± 0.06 m (range from 1.70 -- 1.86 m), and the average body weight was 80.0 ± 6.9 kg (range from 70 to 90 kg).

Experimental environment

Measurements were performed by both methods simultaneously. The method used for combining both dynamic and kinematic measurements of mechanical power output was kinematic motion analysis (system Qualysis*) for obtaining of a dumbbell position in space and time. Eight video cameras captured motion of selected points on the load at a 240 Hz frequency. For direct force measurement, a dynamometer **AMTI was used, with a data frequency of 1000 Hz. The ID method use an indirect force measurement (FitroDyne Premium (FDP) equipment), which works on the basis of optoelectronic encoders. Silone cord of FDP is fixedly connected to an angular velocity sensor and to the dumbbell. When a dumbbell moves, the translational motion is converted to the rotational motion by means of a moving coil. An obtained analogue signal is converted to a digital record, which transforms angular velocity to translational velocity v. FDP, thus, records dumbbell motion velocity v in a vertical direction (Schickhofer, 2000). FitroDyne Premium FDP was connected to a dumbbell in such a way that the string pointed vertically to the Earth surface. A twelve-bit A/D converter connected the FDP to a compatible computer, which recorded data with 100 Hz frequency.

Protocol

Measurements were performed with each tested person individually. The technique of bench press exercise, by Zatsiorsky and Kraemer (2006), was explained to them and corrected. The motion range was adjusted for each tested person individually, and it was controlled by means of a sound signal in the highest and in the lowest peak of motion trajectory. In the course of mechanical muscle power output measurement, subjects lifted 4 dumbbells at

* - *Oualysis Oqus - 1280*1024 pixels*

** - *BP6001200, AMTI Inc., Watertown, MA, USA and 16-bit analogue converter (Measurement Computing Corporation,ModelPCI-DAS6402/16)*

maximum possible speed with various loads: Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg, a Z4 = 47.7 kg. Measurements began when the dumbbell was up; then carried down, and subsequently lifted upwards. In the course of measurement the extension-contraction cycle of participating muscle groups were maintained. There was a 3-minute break between tests.

Data Analysis

We analysed that part of the motion which showed positive power output. The average power output was detected for every lift with every load.

ID method (FDP):

The necessary factor obtained from FDP was vertical velocity v, when a dumbbell moved upwards. Mechanical power output P, needed for the lift, is calculated from changes of vertical velocity vector (v) of a dumbbell at time (t), and changes of weight of a dumbbell (m) in the following way:

$$P = m\left(\frac{d\boldsymbol{v}}{dt} - \boldsymbol{g}\right)\boldsymbol{v}(t),$$

where g is the gravitational acceleration vector [3]

Combined method (criterion):

By means of a force plate, we obtained values of reaction force F_x, F_y, F_z . Kinematic analysis provided us with velocities v_x, v_y, v_z. Scalar product of two vectors of velocity and force determined mechanical muscle power output P. We selected only positive values of power output obtained in the course of upward motion of a dumbbell. The calculation was performed with MATLAB 7.0 software.

Statistical Analysis

Validity of mechanical muscle power output measurement with the ID method, in comparison to the selected criterion, was estimated by means of Spearmen´s Rank Correlation Coefficient r. Factual importance of differences in average values of power output, force and velocity measured by the ID method, in comparison to the selected criterion, was assessed by ES – effect of size (Thomas, Nelson & Silverman, 2005). Average mechanical power output measured by both methods was determined for every load weight Z1, Z2, Z3 and Z4, separately. Analysis was calculated by SPSS 15 software.

Results

In Figures 1 and 2 below, we can see instantaneous velocity and force measurement in the course of the bench press exercise, via the inversion dynamics method ID, in comparison to the selected criterion.

Instantaneous velocities dependent on time measured by both methods showed identical behavior (Figure. 1). Instantaneous force measured by the ID method is, in comparison to the selected criterion, under-valued throughout nearly the entire concentric action in all loads. The instantaneous force under-valuation effect with the ID method is strong, especially for loads Z1 and Z2 (Figure. 2). For loads Z1, Z2 and Z3 we observed negative values of in-

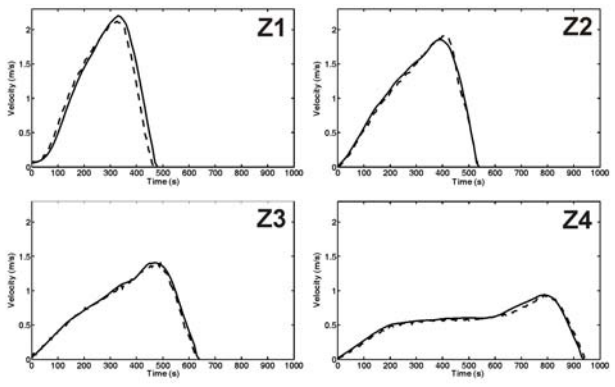

Fig. 1

Instanteous velocity in dependence on time measured by ID method in comparison to the selected criterion (combined method) for one of the tested persons (Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg and Z4 = 47.7 kg). Dashed curve shows values of instanteous velocity measured by combined method and unbroken curve shows values measured by ID method.

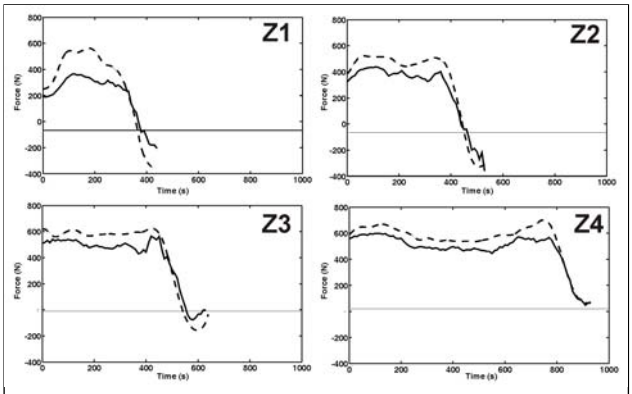

Fig. 2

Instanteous force in dependence on time measured by indirect method ID in comparison to the selected criterion (combined method) for one of the tested persons (Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg and Z4 = 47.7 kg). Dashed curve shows values of instanteous force measured by combined method and unbroken curve shows values measured by ID method.

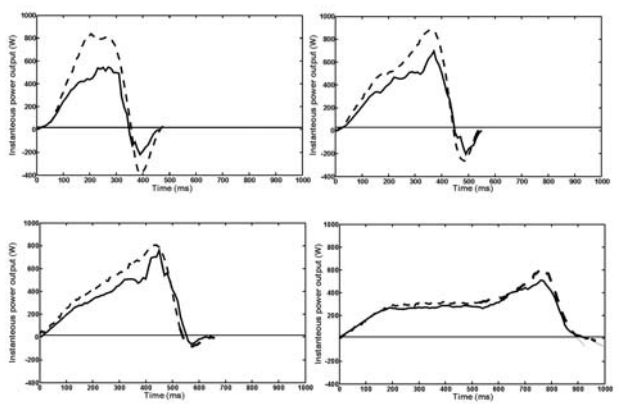

Fig. 3

Instanteous mechanical power output measured by indirect method ID in comparison to the selected criterion (combined method) for one of the tested persons (Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg and Z4 = 47.7 kg). Dashed curve shows values of instanteous power output measured by combined method and unbroken curve shows values measured by ID method.

stantaneous force at the end of concentric action.

Values of mechanical power output measured at bench press exercise by inversion dynamics method ID, in comparison to the selected criterion, can be seen in Figure 3. The ID method under-values instantaneous mechanical power output at all loads Z1-Z4. With rising loads, the curve of instantaneous power output, measured by the ID method, converges to the criterion curve and under-valuation of instantaneous power output declines. For loads Z1, Z2 and Z3 it can also be observed a negative instantenous power output in the final part of concentric action.

A comparison of the ID method to the selected criterion for measuring average values of force, velocity and power output, in the course of bench press exercise in all tested persons, is summarized in Tables 1, 2 and 3.

In selected test groups we did not observe any significant influence of the measurement method on the average value of velocity for all loads Z1-Z4 (average ES=0.29) (Table 1). Average force measured by the ID method, in comparison to average force measured by the combined method, was significantly lower for all loads Z1-Z4, namely on average by 59.80 ± 40.16 N (average ES=1.34) (Table 2). Average mechanical power output measured by the ID method was significantly lower for loads Z1 and Z2, in comparison to average mechanical power output measured by the combined method. Factual significance is confirmed also by effect of size (ES_{Z1}=1.41 and ES_{Z2}=0.59). Correlation coefficients r estimate a satisfactory validity of measurement, especially for loads Z3 and Z4 (Table 3).

Discussion

The aim of this study was to verify validity of mechanical muscle power output measurement in the course of bench press exercise, which uses indirect measurement of force. Cormie et al. (2007) performed a validization study for exercise countermovement squat, with similar equipment to the FDP. As the most accurate method of maximum mechanical muscle power output measurement, they considered a combination of kinematic and dynamic methods.

In measuring average velocity by means of the ID method, with loads Z1-Z4, there were no significantly detected differences in comparison to the selected criterion (Table 1). Instantaneous velocities, dependent on time, showed identical behavior in both methods (Figure 1). It is necessary to mention that FDP measures velocity only in the vertical direction and the criterion measures it in all axes - x, y and z. This implies that horizontal and medial-lateral components do not play much of a significant role in bench press exercise.

The ID method (FitroDyne Premium) detected lower values of instantaneous force than the criterion, throughout nearly the entire range of motion

Table 1

Effect of size index for comparison of ID method to the criterion (combined method) for measurement of average load velocity (m/s) with weights of loads Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg, and Z4= 47.7 kg (n = 10).

Load	Criterion Velocity±sd (m/s)	ID method Velocity±sd (m/s)	Δv (m/s)	ES
Z_1	1.14±0.85	1.17±0.09	-0.03	0.35
Z_2	1.00±0.12	1.05±0.10	-0.05	0.41
Z_3	0.81±0.11	0.85±0.13	-0.04	0.36
Z_4	0.66±0.20	0.67±0.24	-0.01	0.05

Legend: sd – standard deviation, Δv – difference in average velocity difference, ES –effect of size

Table 2

Effect of size index for comparison of ID method to the criterion (combined method) for measurement of average force (N) with weights of loads Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg, and Z4= 47.7 kg (n = 10)

Load	Criterion Force±sd (N)	ID method Force±sd (N)	ΔF (N)	ES
Z_1	350.51±33.62	283.69±35.17	66.83	1.98
Z_2	424.36±40.65	368.91±35.59	55.45	1.36
Z_3	508.75±63.42	451.09±41.07	57.65	0.90
Z_4	551.55±52.44	492.25±30.97	59.30	1.10

Legend: sd – standard deviation, ΔF – difference in average force (n=10), ES – effect of size

(Figure 2). Average values of force in the test group, for all loads Z1-Z4, showed significant differences in comparison to the criterion (Table 2). Average force measured by the ID method was significantly lower in comparison to the criterion for all loads Z1-Z4, on average by 59.80 ± 40.16 N (average ES=1.34). When considering that forearms and upper arms together constitute approximately 9.2% of the total body weight, for an average body weight of tested subjects of 80 kg, it means that weight of the upper limbs is approximately 7.36 kg. The average gravitational force of upper limbs segments on tested subjects of 72.20 N, corresponds to the measured difference of approximately 59.80 ± 40.16 N. Upper limbs do not participate as a whole on bench press exercise.

Since the ID method disregards weight of the moving body, in the course of motion we record lower instantaneous force values. Upper limbs, in the course of bench press exercise, do not move parallel to a dumbbell. It is difficult to estimate which forces are generated at rotational motions in the humeral and cubital joint, in the course of bench press exercise.

The ID method under-estimates instantaneous mechanical power output, in comparison to the criterion, for all used loads Z1-Z4 (Figure 3). With increasing load, the curve of instantaneous power output measured by the ID method converges to the criterion curve, and under-estimation of instantaneous power output decreases (Figure 3). It is obvious that differences in measured power output are due to indirect force measurement used in this method, because motion speed, in comparison to the criterion, did not show any significant differences. At higher accelerations of body segments, the differences in measured power output between the ID method and the criterion increase. Higher accelerations appear at lighter loads (Z1 and Z2). At these loads, one can observe lower correlation coefficients r= 0.50 for Z1 and r= 0.70 for Z2, than at loads Z3 (r= 0.90) and Z4 (r= 0.95). Production of power output at lighter loads is, assumedly, significantly influenced by weight of moving body segments. With heavier loads, a dumbbell is lifted in almost uniform rectilineal motion.

Average mechanical muscle power output measured by the ID method was significantly lower in comparison to the criterion for loads Z1 and Z2. Factual significance is also confirmed by effect of size (Table 3). Correlation coefficients r estimate satisfactorily the validity of measurement, especially for loads Z3 and Z4 (Table 3). Our findings are in accordance with a research performed by Hori et al. (2007), who proved that the ID method under-estimates measured power output in comparison to the combined method ($p < 0.01$), which Cormie et al. (2007) set as a criterion. It is also necessary to take into account the measurement error in individual measurement instruments. For measurements performed by the combined method, we estimated – by

Table 3

Effect of size index for comparison of ID method to the criterion (combined method) for measurement of average force (N) with weights of loads Z1 = 18 kg, Z2 = 26.5 kg, Z3 = 39.2 kg, and Z4= 47.7 kg (n = 10)

Load	Criterion Power output ± sd (W)	ID method Power output ± sd (W)	ΔP (W)	*R*	ES
Z1	378±46	313±40	65 *	0.50	1.41
Z2	419±66	380±65	39*	0.70	0.59
Z3	410±76	390±77	20	0.90	0.26
Z4	357±112	347±124	10	0.95	0.08

Legend: sd – standard deviation, *r* – Spearmen´s correlation coefficient, ΔP – difference in average power output (n=10), ES –effect of size. Significant differences are indicated by *.

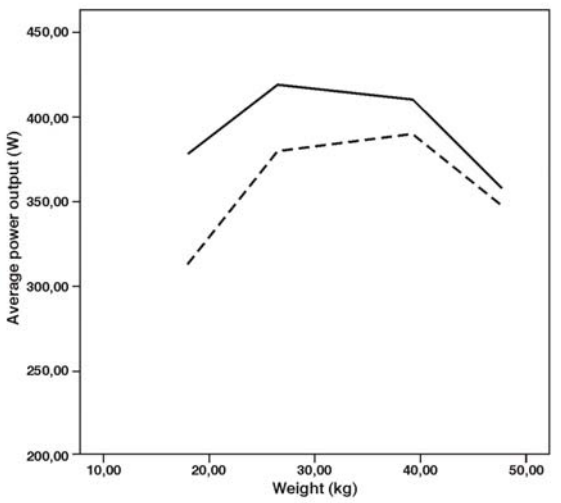

Fig. 4

Comparison of ID method and the criterion at measurement of average mechanical muscle power output, with changing load

means of Uncertainty Propagation Law (Vdoleček, Palenčár & Halaj, 2001) – a relative uncertainty 0.9%, while for the ID method it was 2% from the measured value of power output.

For loads Z1, Z2 and Z3 we also observed negative instantaneous power output in the final part of concentric action. This phenomenon is caused by the examiner's instruction not to drop the dumbbell at the end of the motion. Inertial force of accelerated mass is oriented in direction of original dumbbell motion, and it causes a reaction force which acts in opposite direction (contrary to the gravitational force). Negative power output should not be calculated into final average power output.

For load optimalization in the course of resistance training, trainers need to know the load weight, at which maximum mechanical power output is produced. We also made an effort to determine how the method of measurement influences the optimum load for achieving the maximum mechanical muscle power output. From comparison of the relation between load and power output in Figure 4, we can see that optimum load value for the ID method is approximately 39 kg, while for the criterion it is 27 kg. Therefore, the ID method assumedly over-estimates optimum load for achieving maximum mechanical muscle power output P_{mm}.

Conclusions

When we compared measurement of average motion velocity in the course of bench press exercise, with loads 18-47 kg, in the ID method and the criterion (a combination of kinematic and dynamic methods), we did not observe any significant differences. When we compared measurement of average force exerted in the course of bench press exercise, with loads 18-47 kg, by the ID method to the criterion, we observed significant differences. The ID method under-estimated the measured force throughout the range of selected loads. During verification of validity for mechanical power output measurement by the ID method, in comparison to the criterion, in the course of bench press exercise we concluded that mechanical muscle power output is under-estimated, especially in the lower range of loads. One of the results of this under-estimation is, for example, inaccurate estimation of optimum load for achieving maximum mechanical power output by means of the ID method. However, this does not imply the ID method is not valid. This method can be very effectively used for measurement of power output applied on an object (external power output). Its advantage is that it can be used directly in training practice, therefore, it is necessary to implement physical corrections when this method is used for mechanical muscle power output measurement, so as to better estimate mechanical muscle power output. The most accurate determination of mechanical muscle power output is a method which takes into account the dynamics and kinematics of limb motion in the course of a given exercise. For this reason it is necessary to create a mechanical model for each exercise which will help measure the velocity of the center of gravity of a system (dumbbell+body). Provided we know the accurate differences in estimation of mechanical muscle power output obtained by both the ID method and the combined method, which takes into account dynamics and kinematics of limbs participating in motion, we can create corrections of the ID method in such a way that it will be usable in training practice at load optimalization for demands of power training..

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