IMPACT OF THE JOINT ANGULAR POSITION ON THE PEAK TORQUE OF ELBOW FLEXORS AND EXTENSORS IN HEALTHY MALES

(Original scientific paper)

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Abstract
The aim of this study was to investigate the influence of the joint position on elbow flexors and extensors torque in healthy individuals and to compare the modeling of peak torque-angle relationships with polynomial functions and cubic splines. Fifteen male volunteers (between 19 and 24 years) were measured anthropometric parameters and peak isometric-torque with isokinetic dynamometer at the following angles: 10, 20, 30, 45, 60, 75, 90, 105, 115 and 125°. It was found that the maximal peak-torque (Nm) is generated at 75° in flexors and extensors at significant increase (p <0.05, one way ANOVA, Bonferoni post hoc test) in angular positions between 45° and 75° as compared with the rest angles tested. The torque of the flexors was greater than that of the extensors (p <0.05) in the area of the flexion, within the range of 90°-115°. The maximal isometric force decreased in a narrow range and never fell below 60% with the extensors and 70% with the flexors at any of the tested angles. It was established a moderate correlation (r>0.5, coefficient of Pearson) in both muscle groups between: - height and peak torque (at 30° and 45° for extensors and 115° for flexors); and - muscle mass and torque (at 45° for extensors and 105°, 115° and 125° for flexors). It was only with the flexors, that moderate to significant correlations were observed between peak torque and body mass (105° and 115°), lean body mass (105°, 115° and 125°) and body mass index (105°). The modeling of peak torque-angular position relationship with polynomials of fourth degree was considered optimal, according to the two criteria applied, only for extensors. With the flexors the assessment by the two criteria was ambiguous. The approximative curves in modeling with polynomials did not cover all points, including the maximum peak torque, which is not the global maximum of the optimal function. However this was achieved by interpolating cubic spline curves. It was found in the present study, that the peak, isometric-torque of the elbow flexors and extensors in healthy males: (1) is maximal at the angular position of 75° and is not reduced by more than 30% with the flexors and 40% with the extensors, at any of the tested positions; (2) correlates with anthropometric parameters, which is most manifested for the height and muscle mass in both muscle groups; and (3) is preferable to be modeled with cubic splines, compared to polynomial functions. The specifics of the torque profile as a function of the angular position is determined by the initial length of the muscles and their synergic contribution to the net torque.

Keywords: elbow flexors; elbow extensors; torque-angle relationships; polynomials; cubic splines.

INTRODUCTION
It is known that changes in the joint position have a significant impact on the maximal isometric force that muscles can generate (Murray, Delp, & Buchanan, 1995; Linnamo, Strojnik & Komi, 2006). These aspects are the subject of fundamental and applied research in terms of muscle groups in different joints, including the elbow flexors and extensors, because: - they clarify the role of the joint angle, concerning variations in the static strength in healthy people (Griffin, 1987; Singh, & Karpovich, 1996; Ettema, Styles, & Kippers, 1998); - they allow us to describe and analyze the relationship between the net torque and the angular position from a biomechanical point of view (Frey Law, Xia, & Laake, 2009); - they allow comparisons in clinical and ergonomic studies to be made (Steenbekkers, & Van...
Beijsterveldt, 1998; Ada, Canning, & Low, 2003; Brolin, Hanson, & Högborg, 2014) or they serve as comparative data in the field of sports training for assessment of force performance and norms within athletes (Ramsay, Blimkie, Smith, Garner, MacDougall, & Sale, 1990; Labarque, Eijnde, & Van Leemputte, 2002).

The classical biomechanical relationship length-force is usually examined on isolated muscle preparations, where the length of the sarcomere and the amount of overlapping between actin and myosin filaments within a sarcomere, play a crucial role. At the level of a whole muscle, the relation is transformed into a parabolic curve because of the involvement of both contractile proteins and passive elastic components (Enoka, 2002). At the next level of organization - a muscle group moving single-joint system, the force is transformed into a moment of force or the so called torque. In this case the force of the individual fiber or whole muscle is part of the net torque of a muscle group, which moves the joint. That is why, during the registration of a static, isometric torque in different joint angular positions by means of isokinetic dynamometer, this relationship is transformed into torque-angle relationship. The modeling of the torque-angle relationship reveals the behavior of the muscle groups, but the analysis of the parameters, which determine it is more complex and refers to factors such as: the architecture of muscles, the changes in moment arms of the separate muscles depending on the joint angle, the joint biomechanics, the appearance of the so-called muscle synergy, etc. (Noble, 1980; Frey-Law et al., 2009; Murray, Buchanan & Delp, 2000).

There are significant differences in the maximal peak torque and in the position in which it is generated in a number of studies on torque-angle relations in elbow flexors and extensors with isokinetic dynamometer in the pertinent literature. Relatively little is known about the presence of correlations between torque and basic anthropometric parameters. The lack of such experimental data about the elbow joint is discussed in publications on digital modeling of the human hand (Brolin et al., 2014).

In mathematical modeling of torque-angular position relationships of elbow flexors and extensors, the most commonly used and discussed are mainly the polynomial functions of various degrees (Loof, & Frey-Law, 2013; Pinter, Robbert, Knoek van Soest, & Smeets, 2010), but the results are contradictory and inconclusive. Few authors compare different optimization criteria when modeling such relations with polynomials (Mavrevski, 2014). On the other hand the existing experimental data on modeling these relationships with cubic splines are surprisingly very few yet.

The aims of this study are: - to investigate and describe the effect of elbow joint position on the net peak torque of flexors and extensors, as measured by isokinetic dynamometer in isometric contraction in healthy men; - to examine the correlations between the peak-torque and the anthropometric parameters; - to compare the modeling of peak torque - angle relationship with polynomial functions and with cubic splines.

**METHODS**

Fifteen healthy men aged between 19 and 24 years old without a history of musculoskeletal diseases and a family history of such, in apparently good health, participated in the study, after signing an informed consent. The experiments were conducted at the Center for Functional Research in Sports and Kinesitherapy at the South-West University „Neofit Rilski”, Blagoevgrad. The individuals visited the centre twice: - the first time in order to be conducted medical examination, anthropometric measurements and probation with isokinetic dynamometer; and – the second time in order to be measured the peak isometric torque of elbow muscle groups.

The anthropometric indicators height (cm), body mass (kg), fat (%), lean body mass (kg), muscle mass (kg) and body mass index (kg/m²), were measured with impedance body mass analyzer (IOI 353).

The torque, which is generated in the elbow, during flexion and extension of the forearm, was recorded with isokinetic dynamometer (Biodex System 4 Pro), after a preliminary 5-7 min warming-up before the testing. In the Biodex test chair, the subjects were properly secured by using straps, in order to minimize extraneous and compensatory movements and trunk rotation. The test was conducted on the dominant arm, which was right in all of the individuals. The elbow joint center of rotation (i.e. lateral epicondyle) was approximately aligned with the center of rotation of the dynamometer, together with an elbow attachment. In connection with differences in the muscle mass of the upper arm in the respondents, the range of motion was set by the position of full extension (0°) to that position of maximal flexion, which could be achieved by all respondents and which allows measurement at maximum isometric contraction. That position, in this case, was 125°. The range of motion of individuals with more gracile habitus was 5°-0°-0-150°. The shoulder was maintained at approximately 30° flexion and 30° abduction and the forearm was fixed in a neutral position between pronation and supination. The peak torque generated at maximal, voluntary, isometric contraction in a concentric mode was randomly measured at the following ten angular positions covering a normal range of motion in the joint: 10, 20, 30, 45, 60, 75, 90, 105, 115 and 125°. In each angular position the subjects performed 4 maximal voluntary contractions, lasting 3 sec, alternatively between flexion and extension (two in each direction) with 30 sec rest intervals between repetitions. The intervals between the angular positions were 60 sec. The peak torque indicates the torque produced during maximal voluntary contraction at any angular position, while the maximal torque (or maximal peak torque) refers to the highest value of the peak torque.

**Statistics and mathematical modeling.** The experimental data were processed by different statistical and mathematical approaches. The means, standard devia-
tion and the coefficient of variation are calculated with descriptive statistics. The torque values are presented not only in Nm, but as a percentage as well, by normalization procedure in which 100% is the maximal value of the peak torque, produced at maximal voluntary isometric contraction, at the corresponding elbow joint position for each person. Correlations using Pearson coefficient were used to see the relation between values of body composition or anthropometric parameters and peak torque values at different angular positions. Torque-angle variables were compared between groups using one-way ANOVA. Statistical significance for all tests was set at p<0.05. The following two approaches were applied for modeling of the peak torque-angular position relationship: (a) fitting with polynomials of second, third, fourth and fifth degree, by the method of least squares; after finding the relevant optimal fitting polynomials of the respective degrees it was used two criteria for determining the optimal model: Akaike’s information criteria (AIC) and Bayesian information criteria (BIC); the optimal model, according to the criterion AIC or BIC is assumed to be the one, for which the value of the respective criterion is the lowest; and (b) interpolation with cubic splines. The statistical analysis and graphical presentation of the data was done with the software package Prism 3.0, while the calculation of the criteria was done with Matlab (R2009b).

RESULTS

The average values of the anthropometric parameters

Table 1. Anthropometric data (mean ±SD) of the healthy males (n=15), who participated in the study.

<table>
<thead>
<tr>
<th>Statistical parameters</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Fat mass (%)</th>
<th>Lean body mass (kg)</th>
<th>Muscle mass (kg)</th>
<th>Body mass index (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>21.13</td>
<td>175.9</td>
<td>70.90</td>
<td>17.47</td>
<td>58.34</td>
<td>54.70</td>
<td>22.91</td>
</tr>
<tr>
<td>± SD</td>
<td>1.30</td>
<td>3.93</td>
<td>6.54</td>
<td>4.57</td>
<td>4.34</td>
<td>4.44</td>
<td>1.86</td>
</tr>
<tr>
<td>V (%)</td>
<td>6.16</td>
<td>2.24</td>
<td>9.23</td>
<td>26.16</td>
<td>7.44</td>
<td>8.13</td>
<td>8.13</td>
</tr>
</tbody>
</table>

Figure 1. Peak isometric torque (mean±SD; Nm) of elbow flexors and extensors in the range between 10° to 125° in untrained males. *Significant differences (p<0.05) in both muscle groups, in relation to the torque in the range of 10°- 30° and 90° - 125°; **Significant differences in relation to the extensor’s torque in the same angular position (one-way ANOVA, Bonferroni post hoc test).

Table 2. Correlations between peak isometric torque of elbow extensors or flexors with anthropometric parameters.

<table>
<thead>
<tr>
<th>Elbow extensors:</th>
<th>Correlations</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Height (cm) and peak torque (Nm) at angular position 30°</td>
<td>0.543</td>
<td>0.036</td>
<td></td>
</tr>
<tr>
<td>- Height (cm) and peak torque (Nm) at angular position 45°</td>
<td>0.578</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td>- Muscle mass (kg) and peak torque (%) at angular position 45°</td>
<td>0.522</td>
<td>0.046</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elbow flexors:</th>
<th>Correlations</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Height (cm) and peak torque (Nm) at angular position 115°</td>
<td>0.607</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>- Body mass (kg) and peak torque (Nm) at angular position 105°</td>
<td>0.604</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>- Body mass (kg) and peak torque (Nm) at angular position 115°</td>
<td>0.599</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>- Body mass (kg) and peak torque (%) at angular position 105°</td>
<td>0.691</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>- Body mass (kg) and peak torque (%) at angular position 115°</td>
<td>0.589</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>- Lean body mass (kg) and peak torque (Nm) at angular position 105°</td>
<td>0.628</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>- Lean body mass (kg) and peak torque (Nm) in angular position 115°</td>
<td>0.709</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>- Lean body mass (kg) and peak torque (Nm) at angular position 125°</td>
<td>0.519</td>
<td>0.047</td>
<td></td>
</tr>
<tr>
<td>- Muscle mass (kg) and peak torque (Nm) at angular position 105°</td>
<td>0.629</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>- Muscle mass (kg) and peak torque (Nm) at angular position 115°</td>
<td>0.699</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>- Muscle mass (kg) and peak torque (Nm) at angular position 125°</td>
<td>0.519</td>
<td>0.047</td>
<td></td>
</tr>
<tr>
<td>- Body mass index (kg/m²) and peak torque (%) at angular position 105°</td>
<td>0.664</td>
<td>0.007</td>
<td></td>
</tr>
</tbody>
</table>
of the studied healthy men are presented in Table 1. They show: - a homogeneity of the sample with respect to the age and size parameters; and - relatively large variations in fat and fat-related parameters such as body mass, lean body mass, muscle mass and body mass index.

The peak-torque in isometric contraction of extensors and flexors is represented in all tested angular positions in Figure 1. The maximum peak-torque was

![Figure 1. Maximum peak-torque at different angular positions for elbow extensors and flexors.](image1)

*Figure 1. The maximum peak-torque at different angular positions for elbow extensors and flexors.*

![Figure 2. Typical correlations between the peak torque of elbow extensors at angular position 45° and flexors at 115° with the anthropometric parameters height (A) and muscle mass (B).](image2)

*Figure 2. Typical correlations between the peak torque of elbow extensors at angular position 45° and flexors at 115° with the anthropometric parameters height (A) and muscle mass (B).*

<table>
<thead>
<tr>
<th>Criteria for an optimal model</th>
<th>Degree of polynomials</th>
<th>Muscle group</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>Fifth order</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fourth order</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Third order</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Second order</td>
<td></td>
</tr>
<tr>
<td>AIC</td>
<td>44.06</td>
<td>extensors</td>
</tr>
<tr>
<td></td>
<td><strong>29.60</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>38.90</td>
<td></td>
</tr>
<tr>
<td>BIC</td>
<td>17.88</td>
<td>extensors</td>
</tr>
<tr>
<td></td>
<td><strong>16.12</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35.81</td>
<td></td>
</tr>
<tr>
<td>BIC</td>
<td><strong>19.52</strong></td>
<td>flexors</td>
</tr>
<tr>
<td></td>
<td>24.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>27.15</td>
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</table>
registered at 75° in both muscle groups at moderate inter-individual variations. A significant increase (p <0.05, one way ANOVA, Bonferroni post hoc test) of the peak-torque of flexors and extensors is observed in the angular positions in the range between 45° and 75°, as compared to all other angles measured. However, in the field of flexion, the torque of the flexor was greater than that of the extensors, which was statistically significant (p <0.05) in the range 90° - 115°.

Although the maximal peak-torque was achieved at the angular position of 75° (95.3 ± 7.6 % for extensors and 99.1 ± 2.1 % for flexors), with regards to the dynamics of its values in the rest of the angular positions, it was established the following: - the values of the peak-torque % with the extensors, in the area of submaximal extension fell below 70% in an angular position 10° (65.7%) and 20° (67.8), while in submaximal flexion the peak-torque fell below this limit at all angles after reaching 90° and was 60.5 % at 125°; - with flexors, the torque values in all angular positions did not fall below 70%.

The established trends and differences in the muscle strength of the flexors and extensors in different angular
positions, were grounds to seek correlations between the peak-torque in different angular positions and some basic anthropometric parameters. Table 2 presents all correlations found (p < 0.05; coefficient of Pearson) for the two groups of muscles, the most distinctive are shown in Figure 2. The presented correlations show the following: (a) in both muscle groups tested it was found a moderate to significant correlation between the height of the respondents and the peak-torque; in the extensors it refers to the torque in the area of extension, 30° and 45° (Figure 2, Extensors-A), while in the flexors it refers to the peak-torque at 115° flexion (Figure 2, Flexors-A); (b) in both muscle groups it was found a correlation between the muscle mass and the peak-torque in angular position 45° for the extensors (Figure 2, Extensors-B) and angular positions 105°, 115° (Figure 2, Flexors-B) and 125° for the flexors; and (c) only in the elbow flexors it was observed correlations between the body mass and the peak-torque at 105° and 115°, the lean body mass and the peak-torque at 105°, 115° and 125° and the body mass index and the peak-torque at 105°.

The peak-torque-angular position relationships in absolute values (Nm) in the range of the positions measured, modeled with a polynomial function, were assessed by optimality criteria AIC and BIC. Their values with regards to the polynomials from the second to the fifth degrees are presented in Table 3. It is evident that with the extensors, the modeling with a polynomial of the fourth degree is optimal at both criteria. However, the peak torque-angle relationship modeling in flexors was optimal with a second order polynomial according to AIC and with a fifth order polynomial, according to BIC. The same relationships are modeled in both muscle groups with cubic splines. Their graphical representation for all individuals tested, modeled with the optimal polynomial, i.e. of the fourth degree in extensors and of the fifth degree in flexors, according to BIC, and with cubic splines is shown in Figure 3. It is seen that the curves are close to each other due to a moderate inter-individual variation, and have a similar configuration. Visually, the differences between the two types of modeling are expressed in the fact that the approximative curves in modeling by polynomials does not cover all points, as opposed to a cubic spline modeling. This difference in the two cases of modeling of peak torque-angle curves is shown graphically in Figure 4 where the average values of the peak-torque are normalized as a percentage. In this case, the following is observed: (a) the approximating curve of the peak torque-angle relationship, when modeled by polynomials is smooth, but does not pass through the point corresponding to the maximal peak torque of extensors at 75°; i.e. the global maximum of the function does not coincide with the maximal peak-torque; (b) the interpolating cubic spline curve is not smooth, but accurately presents the behavior of the two muscle groups, as far as the maximum values in position 75° are concerned; (c) with both approaches for mathematical modeling a statistical significant increase (p <0.05) of the torque, respectively of the muscle strength of the elbow flexors in the range of flexion between 90° and 125° was revealed as compared to the extensors; and (d) the extensors show greater strength at angular position 45°, but the increase is not statistically significant.

**DISCUSSION**

The anthropometric data of the healthy males studied are heterogeneous in terms of fat and fat-related parameters, because the individuals in the sample who are not actively engaged in sports, probably have anthropometric body composition and somatotype differences. However, as far as the body mass index parameter is concerned, it could be considered that it is not always indicative of overweight and obesity. For individuals with a greater percentage of muscle mass, this index is also increased because it does not make a difference between fat and muscle tissue, which is observed not only in athletes, but also in persons who are not actively engaged in physical exercise (Witt, & Bush, 2005; Goacher, Lambert & Moffatt, 2012). Although the body mass index is accessible because it is easily calculated, those restrictions are widely discussed in the literature and other parameters are recommended for assessment of overweight and obesity, especially in the absence of specialized equipment (Goh, Tain, Tong, Mok, & Wong, 2004; Kuwabara, Ogawa-Shimokawa, & Tanaka, 2011).

In the present study it was found that the angle of the maximal peak torque of the elbow flexors and extensors in the healthy men tested is 75°. The values of the maximal torque in Nm in both muscle groups are similar to those obtained for men in the pertinent literature (Guenzkofer, Engstler, Bubb, & Bengler, 2012; Bober, 2002; Frey-Law, Laake, Avin, Heitsman, Marler, & Abdel-Malek, 2012). Although many authors have studied the torque of extensors and flexors in the elbow joint, there is no unequivocal opinion concerning the angle in which the muscle groups exhibit maximum force, and whether it is the one and the same with the flexors and extensors (Knapik, Wright, Mawdsley, & Braun 1983; Murray, Buchanan, & Delp, 2000; Pinter et al., 2010). The factors that determine these variations may be of different nature, but the test position at the torque registration, is of crucial importance. It is determined mainly by the angle of flexion and the angle of abduction of the shoulder joint and of the fact whether the forearm is pronated, supinated or is in neutral position (Guenzkofer et al., 2011). To these factors may also be added evidence in the literature on the role of gender, age, level of training and the type of predominating effort, the role of the dominant limb, the reliability of the dynamometer, etc. (Harbo, Brincks, & Andersen, 2012; Gordon, Rudroff, Enoka J. A, & Enoka R. M, 2012; Stark, Walker, Phillips, Fejer, & Beck, 2011). With the background of the design selected in this study, 30° flexion and 30° abduction in the shoulder joint, the peak torque of the elbow flexors and extensors occurs in the middle of the range of 0°- 150°, which is the theoretical range of motion in that joint. In studies with the test position similar to the
one which we apply, the maximum peak torque is generated at the same joint angle or close to it (Brondino, Suter, Lee, & Herzog, 2002). For example, in the study of Bober (2002) the maximum peak torque of the elbow flexors and extensors is also generated at 75°, although the measurement is not isometric, but is close to it, and is achieved by isokinetic protocol with a very low speed, in order to avoid accumulation of fatigue. So, it could be assumed that in the standardization of the test position, and also to some extent the contingent studied (narrow ranges of age, gender, level of training, etc.), the angular position variations at which the maximal isometric capacity of flexors and extensors is achieved are not large and its values gravitate around 75°.

The torque values obtained in this study in the range before 75° where the extensors are short and the flexors are long, and in the range after 75°, where there is a lengthening of the extensors and a shortening of the flexors, are in accordance with the basic biomechanical reasons for the length-force relationship of the skeletal muscle (Noble, 1980; Lieber, 2010; Pinter et al. 2010). There is no doubt that it is very important the role of the joint angle and the initial muscle length for the overlapping of actin and myosin filaments, which determines the possibilities of the molecular generator of muscle force or the so-called cross bridge. Although the optimal length of the skeletal muscle depends on the position in which the maximum-torque is induced, when testing the torque-angle relationship, the so-called muscle synergy intervenes, because the net torque of a group of muscles is estimated (Enoka, 2002), which together participate in elbow flexion or extension. Therefore, for the transformation of the length-force relation in the peak torque-angle, it must be considered various factors influencing the net torque in elbow flexion and extension, such as: - the architecture of individual muscles and the related muscle fascicle length, pennation angle, physiological cross sectional area etc.; - the angle of insertion, as a function of the joint angle; - the moment arm, the lever arm etc. (Zhang, & Nuber, 2000; Doheny, Lowery, FitzPatrick, & O’Malley, 2008; Guenzzofer et al., 2011). Murray et al., (2000), exploring the isometric functional capacity of elbow flexors and extensors, demonstrate the mechanical advantage of some muscles to others (different capacity for excursion during movement, differences in moment arms and optimal length, etc.) and an interplay between the architecture and moment arm of the separate muscles at the generation of the net-torque.

An important aspect in the behavior of elbow muscle groups at the generation of a peak torque in different angular positions is the size of the maximal torque decrease at the shortening or lengthening of the muscles. From the results presented, it is apparent that the maximal torque decrease in the range of 10°-125° is 40% for extensors and 30% for flexors. Therefore, the maximum isometric force generated at an angle of 70° drops in a narrow range, and never falls below 60% for extensors and 70% for flexors at any of the tested angles. These data are in correspondence with the literature data for plantar flexors (Cresswell, Löschner, & Thorstensson, 1995) and elbow flexors (Gandevia & McKenzie, 1988), where the muscle strength at a different length does not fall below 60% of the maximum isometric muscle strength. This illustrates the specifics of the isometric strength profile of elbow flexors and extensors, unlike that of other joints. For example, the reduction in the maximum isometric force according to the angle is significantly greater at the knee, and the so-called muscle inhibition in human knee is a function of the increasing muscle force in the respective angular positions, unlike the established permanent inhibition in the elbow at all angles (Brondino et al., 2002). It can therefore be assumed that, the isometric force of the elbow flexors and to a lesser degree of extensors, remains relatively constant throughout the entire range of motion.

The assessment of the ratio between the torque of the antagonistic muscle groups in a certain range of motion of a joint is a proper criterion of balance, which is essential for the smoothness and coordination of movements, as well as for preventing damage to muscles, tendons, joint ligaments, articular cartilage etc. Such data concerning the elbow joint are missing in the literature. The statistically significant increase of the torque of flexors, compared to that of the extensors, in the range of 75°-125°, is appropriate from biomechanical point of view, and in the context of the activities of daily living, as well. On the other hand, however, it shows that in the range of maximum and submaximal elbow flexion, the balance, smoothness and coordination of movement at the elbow in healthy men, is probably provided by the stronger flexors. Similar relationships are found in the flexors of the healthy women from our previous studies (Penecheva, Kokova, & Dencheva, 2013).

With regards to the balance between the flexors and extensors strength in the range of submaximal extension, it could be suggested that in healthy men in this part of the range of motion, it is ensured by the stronger extensors, particularly at the angle of 45°.

In this study it is presented evidence of correlations (at p <0.05 and a coefficient of Pearson r > 0.5) between anthropometric indicators and peak-torque of flexors or extensors in certain positions of the joint angle of the elbow. The correlation found between the height of the respondents and the torque of extensors in position 30° and 45° or flexors in position 115°, reflects the diversity in the strength of elbow, depending on the range of motion, which is determined by the body size. The research in the literature for a correlation between the torque profile and the height of the respondents, respectively body size, in any joint, are very scarce (Steenbeekers, & Van Beijstervelde, 1998). However, they are taken into consideration with the 3D strength modeling of the elbow flexors and extensors, as well as in the design of the so-called digital human modeling (Frey Law et al., 2009; Brolin et al., 2014). Thus, although the differences in the torque of muscle groups of each individual are unique, the correlations between the peak-torque and the height
in elbow flexors and extensors may probably be due to: - the longer lever arm and hence a moment arm, due to longer bones of the forearm, where the insertions are, which requires greater force; and - the need for compensatory ensuring of greater strength in positions where the extensors (30° and 45°) or the flexors (115°) are shorter.

In the literature, there is evidence for the role of muscle volume as the main determinant of the joint torque with respect to the extensors and flexors of the elbow (Fukunaga, Miyatani, Tachi, Kouzaki, Kawakami, & Kanehisa, 2001). The significant correlations established between the total muscle mass of the tested individuals and the torque of the elbow flexors and extensors only in their typical angular positions (45° for the extensors and 105°, 115° and 125° for the flexors) Modeling with cubic splines is poorly investigated as far as the elbow torque-angle relationship is concerned. In this comparative study of modeling with polynomials and cubic splines it was proved that: - with the interpolating curves, which, unlike the fitting ones, cover all points, the main point at which the increasing part of the relation passes into a decreasing one, is actually the point at which the torque value is maximal; - the interpolating curves are not smooth at the points where the torque is assessed. With regard to the smoothness of the curves obtained in modeling with splines, Channon, Crompton, Günther, & Vereecke (2010) consider that additional conditions have to be precised in the points of measure.

CONCLUSION

Based on the results obtained, it can be made the following conclusions about the profile of the peak-torque generated by the flexors and extensors of the elbow at isometric contraction at different angular positions:

(1) The values of the peak isometric-torque (Nm) of the elbow flexors and extensors in healthy men (67.5 ± 11.0 and 62.8 ± 11.0, respectively) is maximal at 75° angular position, and the torque values in the range between 45° and 75° in both muscle groups are significantly higher (p <0.05) than those in the positions corresponding to a smaller or greater initial length. In the area of the flexion in the range 90°-115°, the torque of the flexors is greater (p <0.05) than that of the extensors. The maximal reduction in the elbow torque is in a narrow range, 40% or 30 % in the extensors or flexors, respectively.

(2) Significant correlations are proved between the anthropometric parameters and the elbow peak-torque in both flexor and extensor muscle groups, that are most relevant in terms of the height and muscle mass of the individuals tested. The torque of the stronger flexors in the range between 105° and 115° also correlates (r> 0.05) with other anthropometric indicators such as body mass, lean body mass and body mass index.

(3) The behavior of the isometric peak-torque-angle relationships in the range of motion shows specificity in both muscle groups, which apart from the initial length of the muscle, may probably have resulted from the muscle synergetic involvement in generating of the net torque.

(4) In mathematical modeling with polynomials, the global maximum of the function does not always coincide with the maximal peak-torque. The optimality criteria AIC and BIC must be differentially applied for assessing the particular model in fitting with polynomials. The interpolating curves with cubic splines, although not smooth, model correctly the behavior of the elbow flexors and extensors, according to the angular position.

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REFERENCES


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