Diagnostics of isometric and isokinetic strength in junior elite tennis players within the context of muscular dysbalances

Diagnostika izometrické a izokinetické síly juniorských tenistů v kontextu svalových dysbalancí

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Abstract

This research aims to determine the strength level of muscle groups in wrist and forearm and to assess lateral differences in junior tennis player group (TEN, n = 10, aged 12–14) and a control group of boys who do not perform any sport activity (CS, n=10, aged12–14) by isometric (hand dynamometer GRIP-D TKK 5401, Takei, Japan) and isokinetic dynamometry (dynamometer Humac Norm CSMI, Stoughton, USA) methods. Diagnostics of concentric extension and flexion was carried out in concordance with Ellenbecker methodology (1991) in angular velocities of 90°/s and 300°/s, results are given in Newton metres (Nm).

Data analysis proved substantive insignificant differences between TEN and CS group as long as age, body height and weight are concerned. Isometric dynamometry: using Cohen's d there were proved substantially significant differences in the strength of dominant extremity in favour of TEN group (d = 0.76) and lateral difference in strength level of right and left upper extremity in TEN group TEN (d = 0.60). Isokinetic dynamometry: in angular velocity of 90°/s were proved substantially significant differences between TEN and CS group in the strength of extensors (d = 1.16) and flexors of right wrist (d = 1.33) as well as in extensors (d = 0.83) and flexors (d = 0.99) of left wrist in favour of TEN group. Similarly, there was proved substantially significant lateral difference in strength level of wrist flexors of right and left hand (d = 0.84). In angular velocity of 300°/s there were proved substantially significant differences between TEN and CS group in favour of TEN group, both in right wrist extensors (d = 0.94) and flexors (d = 1.39). Substantially significant differences in favour of TEN group have been proved also in non dominant upper extremity, both in left wrist extensors (d = 1.27) and flexors (d = 1.12). Neither in TEN nor CS group were proved substantially significant lateral differences in strength of wrist extensors and flexors – with the exception of lateral differences between extensors (d = 0.62) in CS group. Values obtained by assessment of extensors and flexors strength ratio in both TEN and CS groups in both angular velocities signal an increased risk of injury incidence in all cases. From conclusions described above, it is obvious that long-term game and training load significantly increases the level of maximal strength in junior elite tennis players in comparison with the group of their peers who do not perform any sport activity.

Abstrakt

Cílem výzkumu bylo zjištění síly svalových skupin zápěstí a předloktí a posouzení laterálních diferencí u souboru juniorských tenistů (TEN, n = 10, věk 12–14 let) a kontrolního souboru nesportujících chlapců (CS, n = 10, věk 12–14 let) metodami izometrické (ruční dynamometr GRIP-D TKK 5401, Takei, Japan) a izokinetické dynamometrie (dynamometr Humac Norm CSMI, Stoughton, USA). Diagnostika koncentrické extenze a flexe byla prováděna ve shodě s metodikou Ellenbeckera (1991) při úhlových rychlostech 90°/s a 300°/s, výsledky jsou uváděny v Newtonmetrech (Nm).

Analýza výzkumných dat prokázala věcně nevýznamné rozdíly diferencí mezi soubory TEN a CS ve věku, tělesné výšce a hmotnosti. Izometrická dynamometrie: pomocí Cohenova d byly prokázány věcně významné rozdíly síly herní ruky ve prospěch souboru TEN (d = 0,76) a laterální diference síly pravé a levé horní končetiny u souboru TEN (d = 0,60). Izokinetická dynamometrie: při úhlové rych-

losti 90°/s byly mezi soubory TEN a CS prokázány věcně významné diference síly extenzorů (d = 1,16) a flexorů pravého zápěstí (d = 1,33), stejně jako u extenzorů (d = 0,83) i flexorů (d = 0,99) levého zápěstí ve prospěch souboru TEN. Rovněž byla prokázána věcně významná laterální diference síly flexorů zápěstí pravé a levé ruky (d = 0,84). Při úhlové rychlosti 300°/s byly mezi soubory TEN a CS prokázány věcně významné diference ve prospěch souboru TEN jak u extenzorů pravého zápěstí (d = 0,94), tak i u flexorů pravého zápěstí (d = 1,39). Věcně významné diference ve prospěch souboru TEN byly prokázány rovněž u nedominantní končetiny a to jak u extenzorů levého zápěstí (d = 1,27), tak i u flexorů (d = 1,12). U souborů TEN i CS nebyly prokázány věcně významné laterální diference síly zápěstí extenzorů a flexorů – s výjimkou laterálních diferencí mezi extenzory (d = 0,62) u souboru CS. Při posouzení poměru síly mezi extenzory a flexory souborů TEN a CS byly při obou úhlových rychlostech ve všech případech zjištěny hodnoty signalizující zvýšenou možnost zranění.

Z výše uvedených výsledků je zřejmé, že vlivem dlouhodobého herního a tréninkového zatížení je úroveň síly juniorských závodních tenistů věcně významně vyšší než u nesportujících chlapců.

Keywords: *Isokinetic dynamometry, isometric dynamometry, muscular dysbalances, prediction of injury, tennis*

Klíčová slova: *Izokinetická dynamometrie, izometrická dynamometrie, svalové dysbalance, predikce zranění, tenis*

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INTRODUCTION

Optimal strength level is an essential pre-condition for achievements in so called speed-power sports. Its diagnostics enables to assess fitness levels, and last but not least it is the basis for establishment of effective training plan focusing the strength enhancement. Strength capacity can be diagnosed by various methods; the most typical one is manual dynamometry (RD) and isokinetic dynamometry (IZO). According to Stark et al. (2011) isokinetic dynamometry is considered as a highly reliable diagnostics method to determine strength capacity, and, Tarek (2011) even considers this method "a gold standard" as long as strength diagnostics is concerned.

Zháněl et al. (2014) classify tennis as the sport with high demands for fitness readiness. Number of authors (Hohmann, 2010; Fernandez-Fernandez et al., 2014) believe that strength is one of the crucial factors that determine the sportsperson achievements in many sports. As Fernandez-Fernandez et al. (2014), Ferrauti et al. (2014), Schönborn (2012) state, strength belongs among factors that significantly affect performance in tennis. Optimal level of general strength establishes essential conditions for balanced body development and represents a base stone for specific strength. This specific strength is pronounced in the power of tennis strokes and locomotion, and thus it enables fast movement of the player within the court as well as leaps in different directions when operating by the net (Hohmann et al., 2010; Schönborn, 2012). Vodička et al. (2016) state that due to asymmetric character of strain the human body is exposed to in number of sports, the muscular asymmetries, especially in upper extremities, might occur. High degree on one-sided strain was found for example in temporal characteristics of games: elite players execute 380 strokes in an hour in average, and they spend 1–5 hours on a court daily either for their training or match (Girard & Millet, 2008; Kovacs, 2006). Christmass et al. (1998) report 48 three-sets games and up to 72 five-sets games, Schönborn (2012) states that an elite tennis player takes part in 16 tournaments in average, where he plays about 80–88 matches, which is about 22,000 strokes per year in matches only! Physical activity of a tennis player is thus connected with significant force exertion in an asymmetric mode and differentiated lateral load on upper extremity strengthens muscle groups in dominant arm and in the final consequence it leads to functional muscular dysbalances. This dysbalance is likely to cause default joints posture, overall tiredness and thus increased the risk of injury incidence.

Injuries to the wrist and elbow occur quite frequently in elite junior tennis players (not only); Safran et al. (1999) report an incidence in 19–25% of junior players both male and female. Authors point to the fact that modern tennis game is characterized by extremely fast and powerful strokes while forehand and serves represent about 75% of all strokes. These lead to hypertrophy of the flexors in dominant side forearm, which might result in one of the most common tennis injury of upper extremity known as tennis elbow. Abrams et al. (2012) state that tennis elbow occurs in 35–51% of adult tennis players, while in some cases, this injury might lead to partial or complete tendon rupture in wrist extensors. We might therefore seek the tennis elbow origin in fast, repetitive movements of wrists and forearm accompanied by repetitive mechanical strain, possible microtrauma and subsequent degenerative changes on common tendon of forearm extensors attached to the lateral epicondyle of the humerus (Dereberry, 1998). Repetitive and fast movements of upper limbs performed by tennis players by each stroke together with frequent eccentric muscular contractions might stand for significant factors in tennis elbow development. (Lieber et al., 1997; Pienimaki et al., 1997; Stegink Jansen et al., 1994). Another risk factor might be eccentric extension of fingers' and wrist extensors in extremely unnatural wrist position which covers faulty kinematic movement patterns especially in backhand stroke execution. (Knudson, 2004). Rossi et al. (2014) refer to connection between tennis elbow and combination of repetitive simultaneous contractions of extensor muscles during the both forehand and backhand grips. Predominant activity of muscle groups of fingers and wrist extensors have been observed in all tennis serves. Goislard et al. (2012) point out to the fact that, the strength developed in racquet grip itself activates fingers extensors and group muscles of wrist. In case of active tennis career, the long-term load on fingers and wrist muscle groups extensors is gradually increasing, which might in extreme cases lead to severe tendon disorders. Frequent injuries of top world players (i.e. Nadal, Del Potro, Federer) set a good example. Alizadehkhaiyet et al. (2009) claim that it is a muscular dysbalance, defined as functional weakening within muscle groups of agonists and antagonists, or prevailing muscle synergy during movement, that is a common reason for tendon and muscle damages. Also Hayot et al. (2014) report, that the injury known as a tennis elbow may originate from insufficient level of adequate strength in fingers and wrist muscles. Authors further alert to the importance to establish an acceptable level of muscular dysbalances in muscle groups of wrist extensors and flexors. Nirschl a Sobel (1981) states that mutual bilateral muscular dysbalances in upper extremities is 5% in recreational and 10 to 15% in elite tennis players.

Brown (2000) claims that ratio of wrist muscles strength (defined as ratio of weaker and stronger muscle groups, i.e. extensors/flexors × 100%) is within the range of 60–70% in dominant extremity. Other authors (e.g. Ellenbecker, 1991; Ellenbecker et al., 1996; Nirschl et al., 1981; Rhu et al., 1988) state that forearm flexors are being increasingly stimulated during the swing phase of service and forehand stroke, which leads to their muscular adaptation. For example the ratio of forearm extensors and flexors examined in team of baseball players was 50–59%, while the ratio in tennis players group was 60–70%. Findings of some authors mentioned above suggest that in mutual comparison of strength level in elite tennis and baseball players, was proved a higher strength level of wrist extensors in tennis player group. Rhu et al. (1988) diagnosed a muscular activity during backhand, forehand and service by electromyography method (EMG) and in concord with findings above, they point to an increased activity of wrist muscles in all given game operations. Nirschl and Sobel (1981) suggest that it is an increased load of wrist extensors and related strength development of this muscle group that may lead to tennis elbow incidence.

Based on a synthesis of knowledge, we have formulated a research plan to diagnose strength level of left and right upper extremity in junior tennis players and in a control group. Further, after assessment of differences between strength levels of left and right upper extremity we attempted to predict the probability of so called tennis elbow development. This information should be of significant importance not only for players and trainers, but also for physiotherapists and sports medicine doctors and they may contribute to tennis elbow prevention.

METHODOLOGY

The aim of the research was to determine strength level of wrist and forearm muscles on both upper extremities and to assess lateral differences in junior elite tennis players in comparison with a control group of boys of the same age who do not perform any sport activities, by using isometric and isokinetic dynamometry methods. Further, the level of lateral differences as possible indicator of upper extremity tennis injury was tested.

With respect to objectives of the study, research questions have been formulated as follows:

I. Isometric dynamometry
1. What is maximal strength level in tennis players group in comparison with the control group.
2. How significant are differences between strength in right (dominant) and left arm.

II. Isokinetic dynamometry
1. What is the strength level of extensors and flexors of right and left wrist in given angular velocities in tennis players group in comparison with the control group.
2. How significant are differences between strength level of extensors and flexors of right and left wrist in given angular velocities in tennis players group in comparison with the control group.

The study was carried out in two groups of 10 probands, i.e. 20 persons in total. The group of 10 junior elite tennis players aged 12–14 was obtained by an intentional choice from tennis clubs in Brno (sample TEN), the control group of boys aged 12–14 who are not registered in any sport club consists of elementary school pupils of Želešice, Brno (Control Sample, CS). All probands reported right upper extremity as the dominant one, they were free of acute or chronic symptoms of tennis elbow, tendonitis or any other upper extremity injury.

Data have been obtained by following methods and devices:
1. Isometric dynamometry was executed by hand dynamometer (GRIP-D TKK 5401, Takei). The subject stood upright with upper limbs along the body and performed standard grips of hand dynamometer alternating right and left hand (i.e. 2 + 2 attempts). Better of two attempts was taken as the value for measurement itself. If the difference between attempts exceeded 10%, the third attempt was executed. Test results are given in kiloponds (kp).
2. A calibrated Humac Norm CSMI (Stoughton, USA) was used for isokinetic dynamometry. Subjects were seated and the test focused on concentric extension and concentric flexion of wrist muscles. Range of motion (ROM) in this testing was determined as 90°. Range of motion was 35° for wrist extension and 55° for flexion. Range of motion as well as testing protocol is in accordance with Ellenbecker methodology (1991). Six gradient submaximal repetitions were carried out prior to measurement itself. The first attempt was familiarization one, followed by

five attempts focusing strength with gradient force performance, so that the strength of each attempt would exceed the previous one of 20%. Which means the last (fifth) attempt reached 100% of maximal strength level. 30 seconds' rest was followed by five repetitions with maximal strength intensity. Maximal values obtained from five executed attempts both for concentric flexion and concentric extension (with the inclusion of the gravitational constant) are considered as the output data. In accordance with Ellenbecker methodology (1991) subjects were tested at angular velocity of 90°/s followed by 300°/s. Velocity of 90°/s enables diagnostics of force component prevailingly, while in 300°/s velocity component of force is being tested. Results of isokinetic diagnostics are given in Newtonmetres (Nm). Data have been processed by STATISTICA 10 and Microsoft Excel software. Substantive significance of differences in observed parameters was assessed by Cohen's d (Cohen, 1988).

RESULTS

Results of data analysis are shown in Table 1 as basic statistic characteristics of anthropometric indicators.

Tab. 1: Basic statistic characteristics of anthropometric indicators.

Group	TEN (n = 10)				CS (n = 10)			
Variables/SCH	M	SD	min	max	M	SD	min	max
Age	13.23	0.51	12.46	14.02	13.04	0.61	12.07	14.13
Height (cm)	161.59	9.22	148.30	176.00	161.50	5.04	151.00	170.00
Weight (kg)	49.57	8.63	37.00	63.20	49.66	7.83	37.70	62.20

Notes:
M ... arithmetic mean SD ... standard deviation
TEN ... group of tennis players CS ... control group

As obvious from table 1, both groups TEN and CS were almost identical as long as basic anthropometric characteristics are concerned; tiny differences have been found in age (difference +0.16 year in favour of tennis players) and also in body height (difference +0.09 cm in favour of tennis players) and weight (difference +0.09kg in favour of control group). Substantive significance of differences in basic anthropometric indicators of both groups TEN and CS was assessed by Cohen's d and did not prove and significant effect.

Results of data analysis obtained from isometric dynamometry in groups TEN and CS (Table 2) represent a starting point to assess the effect of competition and training load to a maximal level of isometric strength in both upper extremities.

Tab. 2: Basic statistic characteristics of results obtained by isometric dynamometry of TEN and CS group.

Group	TEN (n = 10)				CS (n = 10)			
Variables/SCH	M	SD	min	max	M	SD	min	max
P_{max} (kp)	28.72	5.50	20.80	36.60	24.66	5.19	18.30	34.70
L_{max} (kp)	25.70	4.51	20.70	33.30	24.28	4.88	16.50	33.00

Notes (see Table 1):
P_{max} ... maximal strength, right hand
L_{max} ... maximal strength, left hand

Table 2 shows that in tennis players group (in comparison with control group) was diagnosed a higher level of isometric strength in both right (dominant) hand (difference +4.06 kp in favour of tennis players) and left hand (difference +1.42 kp in favour of tennis players). Substantive significance of differences in mean values of strength level between TEN and CS groups assessed by Cohen's d (http://www.socscistatistics.com/effectsize/Default3.aspx) proved substantive significance in differences between strength level in dominant extremity (d = 0.76, medium effect) and low substantive significance (d = 0.30, low effect) in non dominant extremity in favour of tennis players. This fact indicates significant influence of tennis specialization on isometric strength especially in dominant extremity of tennis players, which can be explained by competition and training load on dominant (in this case right) upper extremity of tennis players (this influence is of low significance in case of non dominant limb).

Assessment of strength level from laterality aspect in both groups, i.e. comparison between right and left hand strength is given in Table 3.

Tab. 3: Assessment of substantive significance of differences in results obtained by isometric dynamometry from laterality aspect.

Group	TEN (n = 10)			CS (n = 10)		
Variables/SCH	M	SD	Cohen's d	M	SD	Cohen's d
P_{max} (kp)	28.72	5.50	d = 0.60 (medium effect)	24.66	5.19	d = 0.07 (low effect)
L_{max} (kp)	25.70	4.51		24.28	4.88	

Notes: See tables 1 and 2

Lateral difference in maximum strength of right and left upper extremities was 10.5% in the group of tennis players and merely 1.5% in the control group. Using Cohen's d was prove a substantive significance of difference (d = 0.60, medium effect) in TEN group, which can be assigned to specific sport activity. In CS group was not proved any substantive significance of differences (d = 0.07, low effect). Results correlate with an assumption of higher strength level in forearm muscle group as a response to the specific load (tennis game) that leads to significant muscular adaptation in dominant extremity.

To obtain more accurate information on strength level of wrist muscles in probands, isokinetic dynamometry has been applied. In accordance with Ellenbecker methodology (1991) the level of strength skills of wrist extensors and flexors has been tested in two angular velocities (90°/s, 300°/s). Obtained values enable their bilateral comparison, i.e. assessment of differences in strength level in muscle groups of extensors and flexors.

Table 4 shows basic statistic characteristics of results obtained by diagnosis of strength skills of wrist extensors and flexors for angular velocity 90°/s (groups TEN and CS) which characterizes mainly power workout of wrist muscles.

Tab. 4: Basic statistic characteristics of results obtained by isokinetic dynamometry of wrist in angular velocity of 90°/s.

TEN	90P_EXT	90L_EXT	90P_FLEX	90L_FLEX
M	7.30	6.80	12.80	9.70
SD	2.79	2.56	4.19	3.07
Min	4.00	3.00	8.00	6.00
Max	14.00	11.00	19.00	16.00

CS	90P_EXT	90L_EXT	90P_FLEX	90L_FLEX
M	4.90	5.20	8.00	7.00
SD	0.83	0.98	2.86	2.28
Min	4.00	4.00	5.00	4.00
Max	7.00	7.00	14.00	12.00

Notes:
90P_EXT ... angular velocity 90°/s; right upper extremity; wrist extension
90P_FLEX ... angular velocity 90°/s; right upper extremity; wrist flexion
90L_EXT ... angular velocity 90°/s; left upper extremity; wrist extension
90L_FLEX ... angular velocity 90°/s; left upper extremity; wrist flexion

In comparison with CS group, TEN group showed a higher level of isokinetic strength in right wrist extensors (difference 2.4 Nm) as well as significantly higher level of strength in right wrist flexors (difference 4.8 Nm). High substantive significance of sport specialization influence on strength level of dominant arm was proved both in right wrist extensors in angular velocity of 90°/s (d = 1.16, high effect) and in right wrist flexors in angular velocity of 90°/s (d = 1.33, high effect).

Effect of sport specialization in absolute values of differences is pronounced to a lesser extent if non dominant extremity is concerned (all probands reported the right extremity as the dominant one), in which case the strength difference in left wrist extensors is 1.6 Nm and flexors difference is 2.7 Nm. Even these differences are however substantively significant in left wrist extensors (d = 0.83, high effect) as well as in flexors (d = 0.99, high effect).

In reference to synthesis of knowledge presenting several opinions on possible connections between muscular dysbalances and increased probability of injury incidence, Table 5 shows results obtained by diagnosis of strength skills of muscle groups of both upper extremities (extensors and flexors in angular velocity 90°/s) in TEN and CS groups.

Tab. 5: Lateral strength difference in extensors and flexors of the wrist in TEN and CS groups for angular velocity of 90°/s.

TEN	90P_EXT	90L_EXT	90P_FLEX	90L_FLEX	dif_DE	dif_DF
M	7.30	6.80	12.80	9.70	0.5	3.1
SD	2.79	2.56	4.19	3.07	–	–
CS	**90P_EXT**	**90L_EXT**	**90P_FLEX**	**90L_FLEX**	**dif_DE**	**dif_DF**
M	4.90	5.20	8.00	7.00	0.3	1.0
SD	0.83	0.98	2.86	2.28	–	–

Notes: see Tab. 4
dif_DE ... difference right/left upper extremity, extensors
dif_DF ... difference right/left upper extremity, flexors

In TEN group a higher strength level of right upper extremity was pronounced both for extensors (90P_EXT × 90L_EXT, dif_DE = 0.5 Nm, 6.9%) and flexors (90P_FLEX × 90L_FLEX, dif_DF = 3.1 Nm, 24.2%). Using Cohen's d there was proved a low substantive significance of lateral differences in extensors strength (d = 0.18, low effect), while, on the other hand a high substantive significance was proved in flexors (d = 0.84, high effect). In CS group was found a higher strength level of left wrist extensors (90P_EXT × 90L_EXT, dif_DE = 0.3 Nm, 5.8%) and a higher strength level of right wrist flexors (90P_FLEX × 90L_FLEX, dif_DF = 1.0 Nm, 12.5%). In both cases was proved low substantive significance of differences both between wrist extensors (d = 0.33 low effect) and wrist flexors (d = 0.38, low effect).

When assessing the ratio of extensors to flexors strength in TEN group there was found a difference of 5.5 Nm (i.e. strength of extensors is at 57.0% of flexors level, difference 43.0%) in right extremity, and 2.9 Nm in left extremity (70.1% of flexors level, 29.9%). In CS group the difference in right extremity extensors and flexors was found as 3.1 Nm (i.e. strength of extensors is at 61.3% of flexors level, difference 38.7%). Difference in left extremity was 1.8 Nm (74.3% of flexors level, difference 25.7%). Table 6 presents results obtained by diagnostics of wrist muscles in TEN and CS groups in angular velocity of 300°/s characterized mainly by power-speed workout of wrist muscles.

Tab. 6: Basic statistic characteristics of results obtained by isokinetic dynamometry of wrist in angular velocity of 300°/s.

TEN	300P_EXT	300L_EXT	300P_FLEX	300L_FLEX
M	7.20	6.60	9.70	8.60
SD	2.56	2.06	2.28	2.76
Min	4.00	4.00	7.00	5.00
Max	11.00	11.00	14.00	15.00
CS	300P_EXT	300L_EXT	300P_FLEX	300L_FLEX
M	5.30	4.70	6.90	6.20
SD	1.27	0.46	1.70	1.25
Min	3.00	4.00	5.00	4.00
Max	7.00	5.00	11.00	8.00

Notes:
300P_EXT ... angular velocity 300°/s; right upper extremity; wrist extension
300P_FLEX ... angular velocity 300°/s; right upper extremity; wrist; flexion
300L_EXT ... angular velocity 300°/s; left upper extremity; wrist extension
300L_FLEX ... angular velocity 300°/s; left upper extremity; wrist flexion

In comparison with CS group, there is apparently higher level of isokinetic strength in right wrist extensors (difference 1.9 Nm) in TEN group and also the level of right wrist flexors proved to be significantly higher there (difference 2.8 Nm). High substantive significance of sport specialization influence on strength of dominant extremity was proved in both extensors (d = 0.94, high effect) and flexors (d = 1.39, high effect) of the right wrist. The effect of sport specialization is again pronounced in non dominant extremity too, since strength difference in left wrist is 1.9 Nm in extensors and 2.4 Nm in flexors.

Both in left wrist extensors (d = 1.27, high effect) and flexors was proved high substantive significance (d = 1.12, high effect) of differences in favour of TEN group. Table 7 presents results obtained by diagnosis of strength skills of identical muscle groups (extensors and flexors in angular velocity of 300°/s) from laterality aspects in TEN and CS groups.

Tab. 7: Lateral strength difference in extensors and flexors of the wrist in TEN and CS groups for angular velocity of 300°/s.

TEN	300P_EXT	300L_EXT	300P_FLEX	300L_FLEX	dif_PE	dif_PF
M	7.20	6.60	9.70	8.60	0.6	1.1
SD	2.56	2.06	2.28	2.76	–	–
CS	300P_EXT	300L_EXT	300P_FLEX	300L_FLEX	dif_PE	dif_PF
M	5.30	4.70	6.90	6.20	0.6	0.7
SD	1.27	0.46	1.70	1.25	–	–

Notes: see tables 4 and 6

In TEN group a higher level of strength in right upper extremity was found both in wrist extensors (300P_EXT × 300L_EXT, dif = 0.6 Nm, 8.3%) and flexors (300P_FLEX × 300L_FLEX, dif = 1.1 Nm, 11.3%). Using Cohen's d proved low substantive significance of lateral differences in the strength of wrist extensors (d = 0.25, low effect) and also wrist flexors (d = 0.43, low effect). In CS group a higher level of strength in right upper extremity was found both in wrist extensors (300P_EXT × 300L_EXT, dif = 0.6 Nm, 11.3%) and wrist flexors (300P_FLEX × 300L_FLEX, dif = 0.7 Nm, 10.1%). Assessment of substantive significance of lateral differences by Cohen's d proved medium substantive significance of laterality influence on wrist extensors (d = 0.62, medium effect) and low substantive significance on wrist flexors (d = 0.46, low effect).

In assessment of ratio strength of extensors to flexors in TEN group, there was found a difference of 2.5 Nm in right extremity (i.e. the extensors strength is at 74.2% of flexor level, difference 25.8%), and 2.9 Nm in left extremity (the extensors strength is at 76.7% of flexor level, difference 23.3%). In CS group there was found a difference in strength of extensors and flexors of right extremity as 1.6 Nm (the extensors strength is at 76.8% of flexor level, difference 23.2%), in left extremity was the difference as 1.5 Nm (75.8% of the flexors strength, difference 24.2%).

DISCUSSION

As mentioned in the synthesis of knowledge, many authors point up a considerable level of muscular adaptation of dominant limb as a result of game and training load typical for elite tennis competition. These findings have been confirmed in our research as well. Regarding low substantive significance of differences in age, body height and weight between the group of tennis players and the control group, the observed differences in upper extremity strength level can be primarily assigned to sport specialization influence, i.e. long-term game and training load.

The observed level of maximal isometric strength in right (dominant) upper extremity in TEN group (M = 28.72 kp) was of considerably higher than (dominant) in CS group (M = 25.70 kp). Also the difference between maximal isometric strength of right and left upper extremity in TEN group was substantively significant (substantive significance was not proved in CS group).

Comparable results of strength in dominant hand of elite tennis players aged 13–14 obtained by hand dynamometer are reported by Reid et al. (2003) medium level M = 29.0 kp. For boys of the same age, Takei (2000) company declares standards of medium strength level as M = 33.3 kp, Beck and Bös (1995) medium value M = 34.13 kp, Carrasco et al. (2010) found in Spanish table tennis players aged 11–13 (i.e. one year younger) medium value as M = 27.44 kp. Values of tennis players group obtained in this research are thus comparable with findings of Reid et al. (2003) and Carrasco et al. (2010). Strength level found in the control group is in all cases lower.

There exist a relatively low number of up to date publications dealing with comparison of results obtained by isokinetic dynamometry method. Our conclusions correlate with Ellenbecker (1991) who tested adult elite players (n = 22) by isokinetic dynamometry (methodology comparable with ours) and found out that tennis players develop significantly higher strength in wrist flexors and extensors of their dominant extremity. Results of his isokinetic testing point out to the fact that repetitive motions in tennis game stimulate strength development in dominant extremity. Likewise, testing of elite junior female tennis players (n = 32) aged 12–16, using adequate methodology, the same author came to significantly higher strength level of wrist flexors and extensors of dominant extremity. Forthomme et al. (2002) as well, conducted his research by application of isokinetic dynamometry method in elite tennis player group (n = 20, aged 23 years) and observed significantly higher strength level of wrist flexors of dominant extremity. The author explains this finding by high muscular adaptation of dominant hand flexors to a long-term game and training activity. Hayot et al. (2014) in relation to frequent incidence of muscular dysbalances in wrist and forearm area (mainly in wrist extensors) in elite tennis players refer to an increased risk of upper extremity injury occurrence and possible development of so called tennis elbow. Literature sources of the past (Nirschl & Sobel, 1981) puts forward a theory that exceeding the limit of 15% difference in strength level between right and left side can be classify as an abnormal dysbalance. In our group of tennis players was found the difference of 25.8% between extensors and flexors strength of the right wrist, and 23.3% difference between extensors and flexors strength of the left wrist. Likewise, there were found comparatively high differences in extensors and flexors strength in the control group: 23.2% in right hand and 24.2% in left hand. Therefore, dysbalances detected in all cases may be considered as abnormal ones. This finding predicts an increased risk of chronic disorders incidence related to muscular dysbalances, such as e.g. tennis elbow.

CONCLUSIONS

Comparison of isometric strength level between tennis players group and the control group proved significantly higher strength level in both right (dominant) and left (non dominant) upper extremities in favour of tennis players. In TEN group there was a substantively significant bilateral difference in maximal strength of right and left upper extremity (d = 0.60, medium effect), which may be assigned to the influence of specific sport activity. In CS group was detected very low, substantively insignificant difference.

Results obtained by isokinetic dynamometry of strength level of wrist extensors and flexors in right hand in both TEN and CS groups in angular velocity of 90°/s proved substantially significant differences in favour of tennis players group both in extensors (dif = 2.4 Nm, d = 1.16, high effect), and flexors (dif = 4.8 Nm, d = 1.33, high effect). Substantially significant differences in favour of tennis players group have also been proved in non dominant extremity both in left wrist extensors (dif = 1.6 Nm, d = 0.83, high effect) and flexors (dif = 2.7 Nm, d = 0.99, high effect).

Analysis of lateral differences in strength level of wrist extensors and flexors (angular velocity of 90°/s) in TEN group proved low substantive significance in case of extensors (dif = 0.5 Nm, d = 0.18, low effect) while in flexors was found high substantive significance (dif = 3.1 Nm, d = 0.84, high effect). In CS group was found a low substantive significance of lateral differences both in wrist extensors (dif = 0.3 Nm, d = 0.33, low effect) and flexors (dif = 1.0 Nm, d = 0.38, low effect). Ratio of extensors to flexors strength in TEN group (angular velocity of 90°/s) proved a difference of 43.0% in right wrist, and 29.9% difference in left wrist. Comparable value of the ratio between extensor and flexors was found in the control group: 38.7% in right and 25.7% in left wrist. Values of each case signal an increased risk of chronic disorder development.

Results obtained by isokinetic dynamometry of strength level of right wrist extensors and flexors in both TEN and CS groups in angular velocity of 300°/s proved substantively significant difference in favour of tennis players group both in right wrist extensors (difference 1.9 Nm, d = 0.94, high effect) and flexors (difference 2.8, Nm d = 1.39, high effect). Substantively significant difference in favour of TEN group have also been proved in non dominant extremity both in left wrist extensors (dif = 1.9 Nm, d = 1.27, high effect) and flexors (dif = 2.4 Nm, d = 1.12, high effect).

Analysis of lateral differences in strength level of wrist extensors and flexors (angular velocity of 300°/s) in TEN group proved low substantive significance both in extensors (dif = 0.6 Nm, d = 0.25, low effect) and flexors (dif = 1.1 Nm, d = 0.43, low effect). In CS group was proved medium substantive significance of lateral differences between extensor (dif = 0.6 Nm, d = 0.62, medium effect) and low substantive significance difference between wrist flexors (dif = 1.0 Nm, d = 0.46, low effect). Ratio of extensors to flexors strength in TEN group proved a difference of

25.8% in right and 23.3% in left wrist. Comparable value of the ratio between wrist extensor and flexors was found in the control group: 23.2% in right and 24.2% in left wrist. Values of each case signal an increased risk of injury incidence.

As obvious from results obtained by isometric and isokinetic dynamometry methods described above, the level of maximal isometric and isokinetic strength in junior elite tennis player group is, due to the influence of long term game and training load, of higher substantive significance than in a comparable group of boys (concerning age, body height and weight) who do not perform any sport activity. With respect to considerable muscular dysbalances found in junior elite tennis player group, it is recommended that trainers and players would integrate compensatory exercises into their training plan, in order to eliminate the risk of injury incidence.

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