THE TENSIOMYOGRAPHY USED FOR EVALUATING HIGH LEVEL BEACH VOLLEYBALL PLAYERS

LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

ORIGINAL ARTICLE

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ABSTRACT

Objective: The aim of this investigation is to obtain information about muscle stiffness, the mechanic and contractile properties of the muscles using the TMG with high level beach volleyball players as well as to demonstrate the usefulness of this method to evaluate the muscles in charge of the knee flexion and extension. Methods: The investigation was carried out with a group of 24 beach volleyball players who took part in the Nestea European Championship Tour - Spanish Master held in the Gran Canaria, May 2009. The method of study used was a comparison of the individual cases of various athletes to ascertain the usefulness of this method in sports. The muscles which were analyzed are: vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) and biceps femoris (BF). Results: Thus, with the information collected we can state the high level of usefulness of this method for the evaluation of muscle stiffness and balance between muscle structures of athletes. However, the validity and reconstruction of the results are conditioned to a strict protocol of evaluation. Moreover, the following criteria should be considered: individuality (the athlete's profile) and specifications (sport characteristics). Conclusions: The application of the TMG to high level players reveals the existence of important differences depending on their different roles in the game (defence, blocker or alternating both roles), the technical actions, the position on court (right-left) and the medical history of injuries.

Keywords: tensiomyography, evaluation of the muscles, symmetries, beach volleyball, stiffness.

INTRODUCTION

The beach volleyball boom had its origin in the Atlanta Olympic Games in 1996. Such sports requires a great variety of techniques, actions played on dry and soft sand which are similar to the ones played in the indoors volleyball (sprints, alterations in direction, vertical jumps…). During each match, there are mean of 85 different actions in approximately 42-45 minutes of game [1,2]. Due to the characteristics of the game, there are certain specific colocations and basic positions which are common to all athletes. Thus[3], the central squat is mentioned as a previous element for the block actions and as a defense position on the court.

The basic premise of the physical training is to develop a solid and balanced muscular structure with the aim to optimize the technical activities as well as reduce the possible risk of injuries during the match. An aspect considered by all coaches in beach volleyball is the unstable surface of the sand[3,4].

The reduced number of players per match, that is, two players in the team, requires that the area defended by each player is bigger (32m^2/player) added to the fact that they cannot be substituted for any another player, increases the needs for conditioning compared to the indoor volleyball. The number of times that player is in contact with the ball is high despite the fact the surface makes fast movements difficult[5-7]mentions that this activity occurs at unfavorable climate conditions (cloudy or sunny days, air temperature, sand temperature and humidity).

Concerning the mechanical point of view, we should emphasize the so called "triple extension mechanism" (ankle, knee and hip joints extension). This fact occurs so that the body is pushed in the direction of the ball in a fast and efficient manner. According to Smith[6], the players use this technique to jump and move as fast as possible towards the ball. However, the fact they are playing on sand limits the actions of the involved muscles on the ankle and significantly alters the movements of the technique.Furthermore, players and coaches should consider this fact once it determines the way and application of force, time and magnitude of fly fore and the vertical jump[8,9].

Such reasons make that an accurate, individualized and localized evaluation of the muscular structures specially involved in the beach volleyball activities are necessary. The tensiomyography (TMG) would be used in this case as an instrument to make information on the musculature which helps us prevent imbalances available, or overload in the musculature, which could be produced by repeated technical actions. Pfirrmann *et al*[10] mention that these cases are possible reasons for many injuries which reduce performance of athletes or even lead to deficiency.

TMG is a non-invasive diagnostic method which does not demand any effort from the individual to whom it is applied. It is used as an evaluation tool for stiffness, the mechanical characteristics and contraction capacity of the surface muscle structures analyzed [11-14]. It measures the geometrical alterations (radial displacement) which occur on the muscular surface during contraction. Subsequently, the results obtained expressed as sensor displacement versus time of activity are used to determine the stiffness and balance between muscular structures, muscular chains (flexion – extension) or extremities (right – left).

The aim of the present investigation is to use the TMG as an instrument to measure the mechanical characteristics of the muscles of volleyball players with the aim to demonstrate the validity of this method for evaluation of the musculature involved with the knee flexor-extensor joint. Moreover, we intended to determine whether the results obtained are sufficiently accurate to use the TMG in the detection of pathologies, asymmetry and specific profiles of players. It should be mentioned that the data obtained are affected by potential injuries, specific technical actions and the position of the player (defense, blocking of game alternative positions during the match) and the game area where the majority of activities is performed (left or right).

METHODS

Sample

Twenty-four players were examined (10 women; 5 of international high level and 5 of international level. 14 men; 5 of international high level, 2 of international level and 7 of national level), all participants in the Nestea- Master Spanish European Tournament, held in the Gran-Canaria island in 2009 (table 1). The most important muscles to be studied were: vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) and biceps femoris (BF).

All participants were told about the possible risks associated with the study and signed a consent form approved by the Committee of Ethics in Research of the ULPGC, following the criteria of the Declaration of Helsinki for research with humans.

Table 1. Morphological characteristics of the sample.

Players	Age	Body weight	Height	BMI	Fat %
	(years of age)	(Kg)	(cm)	(Kg/m^2)	
Men (n=14)	25.14 +/- 6.27	87.50 +/- 5.87	190.71 +/- 5.12	24.06 +/- 1.14	9.54 +/- 1.34
Women (n=10)	25.20 +/- 6.23	68.90 +/- 4.09	176.70 +/- 4.55	22.08 +/- 1.24	12.24 +/- 1.10

Experimental procedures

The TMG has a sensory detector of magnetic pressure which is perpendicularly placed on the surface of the selected muscle [11,15,16]. The pressures has to be the one recommended by the manufacturers[17]. In order to produce muscular contraction, increasing electrical stimuli of one millisecond are applied[18-20]through two electrodes placed on the extremities of the muscle surface (noton the tendons).

The reproducibility of the method and validity of the experimental protocol used by the TMG has been investigated in different studies[12,20-26]

Once the evaluation of the selected muscle is finalized, numerical information on the magnitude of the radial movements of the transversal muscle fibers are obtained[11,20]. The results are presented in the chart (figure 1): maximum radial displacement of muscle belly (Dm), time of contraction (Tc), Time of Delay (Td), Time of sustaining (Ts) and Time of relaxation (Tr).

The maximum radial displacement of muscle belly (Dm) is represented by the radial movement of the muscle surface expressed in millimeters. It presents and evaluates the stiffness of the muscle, with variations between subjects and the manner how their muscular groups developed in the training. Low results, compared with the mean, demonstrate high muscular mass and stiffness[27], while low results represent lack of muscular mass or high muscular fatigue[14,17,22,28-30]. The time of delay (reaction or activation - Td) of the muscular structure analyzed represents the time he took to reach 10% of the total movement. However, it will depend on the predominance of the fiber in this structure of skeletal muscle, his fatigue status[30]and his level of activation[31]. The time of contraction (Tc) is obtained by the determination of the time of interval of the end of the time of reaction (10% Dm) until 90% of the maximal deformation. The time of sustaining (duration of contraction -Ts) is the theoretical time the contraction is kept. With the TMG, it can be calculated (Ts) by the determination of the time interval, since the initial deformation reaches 50% of its maximal value, until the deformation values during the time of relaxation which returns to 50% of the maximal deformation. The time of relaxation (Tr), the time in which the response of the muscle decreases from 90% to 50%, the Dm offers information on the fatigue levels. In any event, if the results were higher than the mean of the individual, there is indication of fatigue. In that case, there is an important correlation between the movement of the muscle belly and the processes of muscular contraction[21].

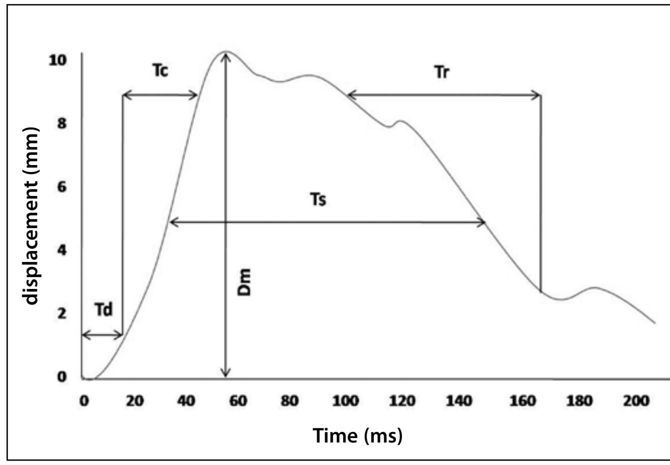

Figure 1. This chart presents the response of the biceps femoris to an electric impulse width of 1 ms and amplitude of 110 mA used with one TMG. Dm represents the maximum muscular displacement. Td is the reaction time to the impulse. Tcis the contraction time in intervals between 10 and 90 % of movement. Ts is the contraction duration. Tr is the relaxation time.

RESULTS

Descriptive statistics by maximum radial displacement of muscle belly (Dm), time of contraction (Tc), Time of delay (Td), Time of sustaining (Ts) and Time of relaxation (Tr) for subjects studied is provided in Table 2.

DISCUSSION

The data obtained in the Dm, Td, Tc, Ts and Tr parameters let us analyze the properties of the muscle, depending on the type of fiber[21], the symmetry (lateral or functional) between the extremities[32-33], the levels of muscular fatigue[28-30,34], or anatomical disorders[28,35,36]. These and other complementary aspects are what we try to explain in the following sections.

TMG and techniques actions

The BF values of both legs are lower than the ones obtained from the knee extensor muscles (VM, RF and VL) in the analyzed sample. High muscular mass of the hamstring muscle may occur

Table 2. Results of the descriptive statistics by Tc, Dm, Td, Ts and Tr of VM, RF, VL and BF obtained from subjects of the sample.

			Right leg					Left leg				
			Tc[ms]	**Dm[mm]**	**Td[ms]**	**Ts[ms]**	**Tr[ms]**	**Tc[ms]**	**Dm[mm]**	**Td[ms]**	**Ts[ms]**	**Tr[ms]**
MALE (n=14)	VM	**Mean**	28.2	8.5	21.3	166.7	64.3	26.4	8.4	21.2	177.5	58.8
		SD	+/- 15.5	+/- 2.0	+/- 1.0	+/- 24.2	+/- 41.7	+/- 10.3	+/- 1.5	+/- 1.7	+/- 24.0	+/- 42.3
		Range	22.7 - 76.8	5.9 - 12.8	19.8 - 23.1	130.7 - 185.4	33.6 - 153.9	21.7 - 57.6	7 - 10.5	18.4 - 23.3	130.3 - 223.5	33.3 - 155.9
	RF	**Mean**	29.2	9.2	23.1	61.7	25.3	31.3	9.2	23.6	64.0	26.0
		SD	+/- 4.7	+/- 3.2	+/- 2.5	+/- 51.1	+/- 45.2	+/- 5.5	+/- 3.1	+/- 1.8	+/- 45.3	+/- 43.1
		Range	22.1 - 37.7	6.6 - 17.9	20.4 - 27.2	37.7 - 186.1	11.7 - 137.9	25.9 - 44.8	5.1 - 16.8	19.4 - 26.2	47.2 - 185.4	16 - 150.7
	VL	**Mean**	26.3	5.6	20.7	50.1	18.4	24.7	6.4	21.0	51.7	19.9
		SD	+/- 3.2	+/- 1.4	+/- 2.4	+/- 40.8	+/- 36.8	+/- 4.3	+/- 1.1	+/- 2.0	+/- 36.2	+/- 31.8
		Range	21.8 - 31.8	3.3 - 8.4	17.9 - 24.3	33.5 - 155.7	9.9 - 127.5	20.3 - 34.8	4.5 - 7.9	18.9 - 25	37.1 - 138.5	10.1 - 103.6
	BF	**Mean**	25.7	3.9	19.4	211.4	56.3	24.2	4.3	20.3	130.6	37.6
		SD	+/- 15.6	+/- 2.4	+/- 4.1	+/- 42.5	+/- 55.4	+/- 12.4	+/- 2.3	+/- 3.1	+/- 70.7	+/- 27.4
		Range	15.5 - 68.9	2 - 9.6	14.3 - 28.3	174.8 - 310.1	33.6 - 220.6	13.7 - 59.5	2.1 - 10.1	15 - 26.9	24 - 297	7.7 - 107.4
FEMALE (n=10)	VM	**Mean**	24.9	7.6	20.7	174.7	74.7	26.4	6.5	20.2	174.5	55.4
		SD	+/- 10.8	+/- 1.2	+/- 1.4	+/- 18.9	+/- 51.5	+/- 11.1	+/- 2.0	+/- 1.1	+/- 27.9	+/- 51.7
		Range	20.2 - 57	6.4 - 9.9	18.7 - 22.6	145.3 - 213.6	40.1 - 163.2	20 - 29.4	4.9 - 11.8	19.1 - 21.3	150.5 - 209.7	31.6 - 167.7
	RF	**Mean**	28.3	8.0	23.2	71.2	29.1	28.7	8.0	22.9	93.1	39.5
		SD	+/- 5.8	+/- 2.3	+/- 2.0	+/- 36.6	+/- 33.9	+/- 4.4	+/- 1.7	+/- 2.0	+/- 49.9	+/- 42.7
		Range	19.5 - 39.7	6 - 13.3	19.4 - 25.8	53.7 - 146.1	17.9 - 110.6	22.5 - 36.8	5.2 - 10.6	18.9 - 26.3	43.1 - 171.9	22.2 - 129.3
	VL	**Mean**	24.6	5.6	20.4	42.3	14.1	24.4	5.5	19.9	42.5	14.9
		SD	+/- 1.2	+/- 1.2	+/- 2.2	+/- 28.7	+/- 25.9	+/- 2.2	+/- 1.0	+/- 1.7	+/- 16.8	+/- 15.0
		Range	23.2 - 26.9	4.4 - 8.2	17.6 - 23.2	32.2 - 128.6	9.1 - 94.5	21.6 - 28	4.7 - 7.6	17.9 - 22.6	33 - 62.9	8.4 - 57.4
	BF	**Mean**	37.6	5.7	22.0	209.6	76.2	32.2	6.4	23.8	195.9	50.4
		SD	+/- 17.5	+/- 2.7	+/- 2.4	+/- 77.4	+/- 30.1	+/- 16.0	+/- 2.0	+/- 2.4	+/- 32.6	+/- 14.1
		Range	18.4 - 69.6	2.8 - 10	18.5 - 24.9	150.8 - 420.3	56.4 - 123.5	16.7 - 70.1	3 - 9.9	20.2 - 27	150.8 - 249.9	29.6 - 73.9

due to two frequent technical actions in each volleyball players; initial reception position (hip joint, folded) and the explosive vertical jump (the extensor muscular chain activates it). Such fact is especially observed in experienced players. Excessive muscular mass produces some imbalance, leading to asymmetry between the knee extensor and flexor muscles, causing pain in the knee joint (table 3).

The connection between agonist and antagonist during knee joint flexor-extensor movements is presented in the table as the percentage of functional symmetry. Normal values are around 65% or more[28,33,35]. These values are used by these authors as reference, collected in an investigation carried out with individuals who practice physical activity with moderation. However, they should be used as guidance, despite being possible to observe in table 3 that there are players with higher values of functional symmetry. In this context, symmetry values may be attributed to two different factors:

- Excessive fatigue or stiffness of the BF muscle;
- Lack of tonus or muscular fatigue of the knee joint extensor muscles (VM, RF, VL).

For instance, the individual called masculine 1 (table 3) presents a Dm of 4.1 mm in the BF of his right leg and 6.6 mm in his left leg. These results may be positive or negative despite being a sign of good muscular tonus. On the other hand, if we compare and consider the extense musculature, there is indication of a possible risk of injury for the player. The RF values are very high for this kind of players (right leg: 17.9 mm, left leg: 16.8 mm). The moderate values which present this characteristic indicate functional asymmetry, causing the frequent low back pain the player has been feeling.

The Dm values of the VL and VM inform on the level of functional symmetry of the knee joint. Patella pain and tendinitis andon the kneecap may be caused by knee instability. If we consider the information about feminine 1 from table 3, we can observe that she may be feeling pain on her right leg, despite the symmetry values being acceptable. 75% right legand 88% left leg. When the relation between VM and VL is analyzed, we conclude that the problem may be caused by a possible imbalance between them (49% right leg and 85% left leg).

Table 3. An example of functional symmetry of the knee joint and possible pathologies associated to 10 subjects (5 men and 5 women). The data in italics present the most important ones.

Players	**Functional symmetry**		**Pain in the leg**
	Right	**Left**	
Male 1	*60%*	80%	Right leg
Male 2	*70%*	92%	Left leg
Male 3	89%	71%	Left leg
Male 4	58%	71%	Right leg
Male 5	82%	89%	No
Female 1	75%	88%	Right leg
Female 2	91%	48%	Left leg
Female 3	*51%*	60%	Both
Female 4	*53%*	71%	Right leg
Female 5	78%	76%	No

TMG and its technical function

The BF is frequently required in defensive actions and in specific movements during competitions. The Dm values of players of long term in this sport (for male and female categories) show that these are lower in specialist in defense. In our sample, the specialists in defense present values of Dm between 2 and 4 mm. On the other hand, the specialists in blocking, who oscillate between the defense and blocking positions, present approximate values between 4 and 8 mm. Previous studies emphasize the reference value of Dm 8.17 mm in untrained subjects[33], while soccer players range between 3 and 8 mm[35].

TMG and the player's position on the court

The functions of the players determine greater involvement of certain muscular structures. We should add to these considerations the position they take on the court as well as the functions they play.

If we revise the duration of the contraction (Ts) of the sample we will realize that the players who compete in pairs present higher fatigue levels in their VL (table 4).

TMG and injury prevention

The possibility that the TMG contributes to the prevention of injuries is high. A priori, it gives us the opportunity to determine high risk situations for future muscular injuries. The interpretation in these cases requires a high level of experience from the side of the evaluator since the TMG results in some cases present similarities between the ideal performance states and states with high risk with potential to injury.

For example, after an intense training session is very common to find the following values in BF: high Ts and Td and low Tc and Dm. These circumstances are obvious because the muscular structures are in optimum conditions to play an efficient mechanical work, but it is also certain that there is high level of fatigue, which could involve a risk for the integrity of the muscle. In these circumstances where the muscles present high stiffness, it is necessary to massage or stretch them (table 5).

Table 4. Example of the maintenance time of the contraction of 4 beach volleyball pairs(2 men and 2 women) for the analysis of their VL dependent on their positions on the court.

Partner	Players	Time of sustaining (Ts - ms)		Position on court
		Right	Left	
A	Male 1	129.2	116.8	Left
	Male 2	36	39.7	Right
B	Male 3	41.2	38.4	Left
	Male 4	61.3	79.1	Right
C	Female 1	128.6	44	Left
	Female 2	43.1	62.9	Right
D	Female 3	41.9	34.2	Left
	Female 4	36.1	42.6	Right

Table 5. Correlation between Ts and Td, Tc and Dm of BF obtained from the subjects of the sample (2 men and 2 women).

BF	Right				Left			
Player	Tc (ms)	Dm (mm)	Td (ms)	Ts (ms)	Tc (ms)	Dm (mm)	Td (ms)	Ts (ms)
M1	18.4	4.1	22	202.9	31.1	6.6	20.7	242.8
M2	32.9	2.9	16	199.9	28.3	2.6	15	234.1
F1	29.8	5.2	21.8	249.5	28.4	8.8	25.4	215.1
F2	18.4	3.8	19	420.3	16.7	3	20.2	249.9

Another application in beach volleyball, as well as in other sports, is the detection of muscular fatigue, for which it is necessary to use more than one variant of the TMG to conduct a personalized diagnosis for each subject. In our viewpoint, we consider that with high levels of fatigue, the time of reaction (Td) should be high, the shortening of the muscle velocity (Dm/Tc) low and the duration of the contraction (Ts) high. Despite of that, we should be careful with the results, especially with the values of velocity shortening because we can face fatigue related with high or low Dm.

Low Dm may be caused due to the high velocity actions which can be derived from high levels of muscular stiffness. If the Dmincreases too much, it can related with a chronic fatigue status or muscular weakness. Another aspect to be considered is that it is not possible to compare comparisons between subjects with no information values and each one of them during their habitual training or competitions, once the time of contraction will depend on the characteristics of the analyzed muscle and the high time of contraction seems to be related to a higher number of type 1 fibers[31].

TMG, injury control and recovery

The TMG may provide data about the progress and effectiveness of the recovery of the injuries.Therefore, we used two examples of study: the recovery processes of a torn cruciate ligament and torn fibers of the BF.

Torn cruciate ligament; the athlete focused his recovery on the strengthening of the hamstrings of his hurt leg (left leg). Despite his morphological balance (thigh diameter of his dominant leg 55.6 cm; non dominant 54.6 cm) his muscular response indicates that there is serious asymmetry. For example, his functional symmetry (flexor-extensor muscles) was imbalanced on his right side (53%) and there is asymmetry between VM and VL of the other leg (48%).

In the case of the athlete with torn muscular fibers of the left leg: this athlete focused his recovery on hypertrophy training: even though, he still presented anomalies on BF of both legs (table 6).

Table 6. This table presents the results of TMG applied to a beach volleyball player who had an imbalanced functional BF.

	Right					Left				
	Tc (ms)	Dm (mm)	Td (ms)	Ts (ms)	Tr (ms)	Tc (ms)	Dm (mm)	Td (ms)	Ts (ms)	Tr (ms)
VM	23.6	6.4	18.7	145.3	117.9	29.4	5.5	19.3	166.7	32.1
RF	31.4	6.9	22.3	56.7	21	34.2	6.6	21.6	109.4	57.1
VL	24.1	5.2	19	43.1	15	24	4.9	17.9	62.9	34.7
BF	35.4	2.8	18.5	197.9	56.4	70.1	8	24.2	168.4	63.2

Table 6 presents mechanical and nervous disorders in both BF. We can specifically observe that the left leg presents Tc, Dm and Td values higher than the right leg. Moreover, the athlete presented imbalance of muscular mass in both legs (diameter of right leg 66cm, and 62cm injured leg).

CONCLUSIONS

The data obtained of the subjects in our sample let us confirm that TMG is a highly useful technique for the evaluation of structures of muscular stiffness and muscular balance of athletes. However, we should remember that the validity and reproducibility of the results are conditioned to strict evaluation protocols. Furthermore, it should be considered that the data interpretation should also respect the individuality criteria (the athlete's profile) and specificities (characteristics of the sport). The application of a high level beach volleyball sample evidences the relevant differences due to different functions of each player (defense, blocking or alternation between both functions), the technical actions, the position on court (right-left) and the player's injury history.

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