ESTIMATED MUSCLE FORCES ANALYZES DURING CONCENTRIC-ECCENTRIC SHOULDER EXTERNAL AND INTERNAL ROTATION

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The purpose of this study was to analyze the muscle force production during eccentric/concentric shoulder internal and external rotation with 90° of abduction. Six male subjects performed five repetitions of maximal concentric and eccentric contractions rotation without interval, with a mean angular speed of 60°/sec. A biomechanical model was implemented to estimate muscle force and moment. Infraspinatus, supraspinatus and teres minor presented the larger peak moment values during external rotation (concentric and eccentric). Subscapularis, pectoralis major and teres minor presented the larger peak moment values during internal rotation (concentric and eccentric). The eccentric contraction allowed larger peak muscle forces and moments and the correspondent angles were altered, if compared to concentric conditions. The results presented are useful as guidelines for shoulder rehabilitation programs.

KEY WORDS: muscle force, optimization model, rehabilitation.

INTRODUCTION:

During shoulder rehabilitation, it is commonly used strengthening exercises for rotator cuff muscles (Hayes, Callanan, Walton, Paxinos, & Murrell, 2002; Tytherleigh-Strong, Hirahara, & Miniaci, 2001). For athletes' rehabilitation, it is commonly suggested to strengthen rotator cuff muscles with the shoulder with 90° of abduction (Kibler, McMullen, & Uhl, 2001; Wilk, Meister, & Andrews, 2002). Eccentric contractions play an important role on tendinopathy rehabilitation (Kibler, McMullen, & Uhl, 2001; Wilk, Meister, & Andrews, 2002). Eccentric contractions present the additional contribution of non-contractile tissues, which permits larger force production magnitudes, if compared to concentric contractions (Herzog, Schachar, & Leonard, 2003). The aim of the present study was to analyze the muscle force production, using a mathematical model, during eccentric/concentric shoulder internal and external rotation with 90° of abduction.

METHOD:

Six male subjects, with a mean age of 25 years (±4), mean height of 1.82 m (±0.09 m) participated in this study. The right (dominant) shoulder was evaluated and none of the subjects reported any history of injury in the evaluated shoulder. All subjects read and signed university-approved informed consent documents for human subjects prior to participation. Data collection was carried out on a Cybex Norm isokinetic dynamometer. The isokinetic dynamometer output signal and the eletrogoniometer were connected to a microcomputer Pentium III 650 MHz using an analogical-digital converter of 16 channels with a sampling frequency of 500Hz. For data processing and filtering, it was used the software Matlab 7.0 ® (MathWorks Inc, Massachusetts - USA), in which the mathematical model was developed. The model was implemented in a personal computer AMD Atlhon, 2.1 GHz of processing speed and 512 MB RAM memory. Before the test, the subjects performed three submaximal internal and external rotation contractions for familiarization with the test. During the testing, the subjects performed five repetitions of maximal concentric and eccentric contractions rotation without interval, with a mean angular speed of 60°/sec. During the experiment, it was requested for the subjects not to move the trunk. The subjects were positioned as recommended by the manufacturer. Angle and moment data were filtered with a digital filter, butterworth, low pass, third order, using the Residual Analysis Method to choose the cutoff frequency (Winter, 2005). After the filter process, an average of the five repetitions was calculated for the angle and moment data. The convention used in this study was the following: negatives values expressed external rotation and positive values internal rotation. Zero angle was defined as neutral position of the upper limb.

The model's algorithm is based on the algorithm proposed by Favre, Sheikh Fucentese, & Jacob (2005). The output data are estimate forces generated by shoulder external and internal rotator muscles. The internal rotator muscles considered in the model were the following: subscapularis (Subs), pectoralis major (PM), anterior deltoideus (AD), latissimus dorsi (LD), teres major (TM) and middle deltoideus (DM). The external rotator muscles considered were: supraspinatus (Ssp), infraspinatus (Isp), posterior deltoideus (PD), middle deltoideus (MD), teres minor (Tm). The model uses as independent variables: internal and external rotation moment (measured on the isokinetic dynamometer), moment arms values of each internal and external rotator muscle, physiological cross-sectional area (PCSA) and muscle stress of glenohumeral muscles (obtained from the literature) (Kuechle et al., 2000) which was assumed to be equal to 70 N/cm^2.

RESULTS:

The external and internal rotation moment arms of each muscle, as well as, the physiological cross-sectional area, are presented at Table 1. The main external and internal rotator muscles are presented at Tables 2 and 3, respectively. Isp, Ssp and Tm presented the larger peak moment values during external rotation (concentric and eccentric). Subs, PM and TM presented the larger peak moment values during internal rotation (concentric and eccentric). The three portions of the deltoid muscle presented small peak moment values.

Table 1 Peak of external and internal rotation moment arms (and its correspondent angles), and physiologic cross sectional area (PCSA) of each external and internal rotator muscles.

	Ssp	Tm	Isp	MD	PD	AD	
PCSA (cm^2)	5.21	2.92	9.51	9.08	9.45	7.38	
ER Moment arm (m)							
Peak	0.0237	0.0294	0.03	0.0345	0.0122	0.0089	
	(91°)	(91°)	(91°)	(91°)	(12°)	(78°)	
	Subs	**PM**	**AD**	**LD**	**TM**	**MD**	**PD**
PCSA (cm^2)	13.5	13.65	7.38	8.64	10.02	9.08	9.45
IR Moment arm (m)							
Peak	0.0170	0.0134	0.0031	0.0121	0.0095	0.0065	0.0021
	(-13º)	(-9º)	(45º)	(-18°)	(45º)	(45º)	(45º)

Ssp: supraspinatus; Tm: teres minor; Isp: infraspinatus; MD: middle deltoid; PD: posterior deltoid; AD: anterior deltoid; Subs: subscapularis; PM: pectoralis major; LD: latissimus dorsi; TM: teres major.

Table 2 External rotation peak moment, muscles peak force and peak moment values and its correspondent angles.

	ERm	Ssp	Tm	Isp	MD	PD	AD
Concentric							
Moment (Nm)							
Peak	-43.2	-5.9	-9.0	-27.8	-0.04	-0.004	-0.07
	(-35°)	(-33°)	(-35°)	(-34°)	(38°)	(39°)	(-36°)
Force (N)							
Peak	-	884.5	495.7	1614.4	31.1	32.4	25.3
		(28°)	(28°)	(28°)	(28°)	(28°)	(28°)
Excentric							
Moment (Nm)							
Peak	-63.5	-8.8	-13.0	-41.1	-0.04	-0.003	-0.09
	(2°)	(-7°)	(5°)	(2°)	(-29°)	(-34°)	(-23°)
Force (N)							
Peak	-	1376.2	771.3	2512.1	48.5	50.4	39.4
		(32°)	(32°)	(32°)	(32°)	(32°)	(32°)

ERm: External rotation moment; Ssp: supraspinatus; Tm: teres minor; Isp: infraspinatus; MD: middle deltoid; PD: posterior deltoid; AD: anterior deltoid.

Table 3 Internal rotation peak moment, muscles peak force and peak moment values and its correspondent angles.

	IRm	Subs	PM	LD	TM	AD	MD	PD
Concentric								
Moment (Nm)								
Peak	69.7 (6°)	25.9 (2°)	20.9 (7°)	11.6 (-0.4°)	10.9 (37°)	0.04 (43°)	0.12 (43°)	0.04 (43°)
Force (N)								
Peak	-	1591.7 (18°)	1609.4 (18°)	1018.7 (18°)	1181.4 (18°)	17.6 (18°)	21.6 (18°)	22.5 (18°)
Excentric								
Moment (Nm)								
Peak	90.6 (-22°)	34.0 (-22°)	26.9 (-22°)	15.6 (-23°)	13.13 (-20°)	0.03 (-38°)	0.08 (36°)	0.03 (36°)
Force (N)								
Peak	-	2029.0 (-24°)	2051.5 (-24°)	1298.5 (-24°)	1505.9 (-24°)	22.4 (-24°)	27.6 (-24°)	28.7 (-24°)

IRm: Internal rotation moment; Subs: subscapularis; PM: pectoralis major; AD: anterior deltoid; LD: latissimus dorsi; TM: teres major; MD: middle deltoid; PD: posterior deltoid.

DISCUSSION:

Internal rotation moment presented larger peak values if compared to the external rotation moment, this was also found by other authors (Cahalan, 1991; Hageman, 1989; Shklar & Dvir, 1995). It is important to remember that the external rotator muscles play an important role on the controlling of sports movements, by contracting eccentrically. That is the reason of strengthening of external rotator muscles is essential to prevent muscle-tendinous injuries (Wilk, Meister, & Andrews, 2002).

The main external rotator muscles were: Ssp, Isp and Tm. During an electromyographic study, similar results were found (Ballantyne et al., 1993). The present study also revealed that the Isp muscle presented the larger peak moment and peak force values. For internal rotator muscles, the main responsible for internal moment production were: Subs, PM and LD. Subs and PM presented similar force and moment values. This can be explained by their moment arms magnitudes, which are extremely similar on their magnitude and behavior (Kuechle et al., 2000).

During eccentric contractions, estimated muscle forces and muscle moments were larger than concentric contractions, besides that, the peak force and peak moment correspondent angle altered, when compared to concentric movements. Those differences between concentric and eccentric contractions are, possibly, related to the contribution of soft tissues (epimisium, perismisium and endomisium) (Herzog, 2003). Force production capacity depends on: contraction condition (isometric, eccentric and concentric), force-speed relationship, temporal and spatial summation of motoneurons (Enoka, 1988; Soderberg, 1997), and force-length relationship (Rassier, MacIntosh, & Herzog, 1999). The interference of those aspects was minimized. Possible variations regarding the force-speed relationship and stimulus summation were reduced, in view of the fact that the angular speed was controlled (60º/sec) and subjects were requested to produce maximum force (Soderberg, 1997). Consequently, the factors capable to interfere on muscle force production capacity were: force-length relationship and contraction conditions. The influence of force-length relationship on muscle force production was also found by other authors for the shoulder muscles during external rotation of this joint (Toledo, Krug, Castro, Ribeiro, & Loss, 2006).

The internal and external rotator muscles presented their peak moment at different angles of the range of motion. The moment production capacity depends on muscle force production and moment arm magnitudes (Rassier, MacIntosh, & Herzog, 1999). Due to the variation of the moment arm magnitudes, the production capacity of internal and external moment may vary along the range of motion. These different behavior permits a shifting on the stabilization role among shoulder muscles. Consequently, different shoulder injuries should have different strengthening rotator cuff programs. For instance, during the rehabilitation process of a supraspinatus injury, the physical therapist should consider: when this muscle presents a larger moment production capacity; when this muscle presents a larger force production capacity and when it develops a stabilization role for the glenohumeral joint. Considering those aspects permits to control the overload imposed at the muscle-tendinous unit and improve the healing process of the soft tissues (Toledo, Ribeiro, & Loss, 2007). At process healing initial stages, peak external loads should occur at range of motions where the muscle develops a stabilization function. As the healing process proceeds, the peak external load should occur around 30° of external rotation (for concentric contractions) and 7º of external rotation (for eccentric contractions).

CONCLUSION:

The eccentric contraction allowed larger peak muscle forces and moments and the correspondent angles were altered, if compared to concentric conditions. The results presented can be used to control the range of motion where maximum external load should be applied to the shoulder muscles. This would ease a better management of the healing process of muscle-tendinous injuries. The results presented are useful as guidelines for shoulder rehabilitation programs.

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