Original Article

Isokinetic shoulder rotator muscles in wheelchair athletes

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Objectives: To assess the influence of wheelchair propulsion and neurological level on isokinetic shoulder rotational strength.

Setting: University of Montpellier, France

Methods: Data were evaluated in three groups of subjects as follows: 12 nonathletes, 15 tennis players and 21 wheelchair athletes. We then compared 12 high paraplegic athletes (HPA) and nine low paraplegic athletes (LPA) within the group of 21 wheelchair athletes: The isokinetic tests were performed in the seated 45° abducted test position in the scapular plane at 60, 180 and 300° s⁻¹ for both shoulders. Peak torque and mean power values were gathered and, from these values, the internal/external rotation ratios were calculated.

Results: Intergroup comparison showed an influence of lesion and sport on peak torque at 180 and 300° s⁻¹ for the internal rotators and significantly higher values of the internal/external ratios in the wheelchair athlete group. For mean power, we observed significant differences under all test conditions and significant differences for ratio only on the dominant side at 180° s⁻¹ and on the dominant side at 300° s⁻¹. Comparison of the two groups of paraplegic athletes showed significantly higher values of peak torque and mean power of the external rotators in the LPA for all test conditions.

Conclusions: Neurological level of lesion does not systematically influence the development of internal rotator muscles; in contrast, the participation of the external rotators appears strongly correlated to neurological level. The comparison of the two sides in the two paraplegic groups showed that in two-thirds of the cases the values of the external rotators were significantly higher than those of the internal rotators on the nondominant side for peak torque and mean power. Ratios on the dominant side were systematically higher than on the nondominant side, with significant differences also noted in two-thirds of the cases. These results raise questions about the influence of neurological level and wheelchair propulsion on the muscular adaptations of the shoulder in wheelchair athletes.

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Keywords: paraplegic; athletes; isokinetic; shoulder; muscular balance

Introduction

The shoulder complex participates in many daily activities. For the wheelchair-bound paraplegic, the scapulohumeral joint is particularly used for repetitive movements and thus undergoes considerable muscle–joint stress. Wheelchair propulsion and depression transfers require adaptations of all the periarticular structures, which were originally developed for prehension or balance. Several studies have reported kinematic analysis of propulsion^{1–3} and muscular activity during

the propulsion cycle.^{4,5} The clinical signs of overuse have been detailed and the relationship between wheelchair propulsion and the development of shoulder pathologies has been investigated.^{6–8} The isokinetic method of quantifying muscular exercise and the agonist/antagonist ratio, which has been useful in research to prevent dysfunction, are two methods to understand the muscular adaptations that occur with athletic activities.^{9–11} The notion of normative values for the internal/external rotator muscle ratio is today an issue of considerable debate. This ratio is hypothesized to be related to overuse, which causes premature degeneration and has led to some criticism of the

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competitive practices of athletes. Further research is needed to determine more clearly the relationship between this ratio and the development of overuse syndromes. For wheelchair users and even more so for wheelchair athletes, we need to determine the influence of wheelchair propulsion and the factors that lead to nonphysiologic adaptations.

The principal aim of this study was to determine the influence of wheelchair propulsion and neurological lesion level on peak torque, mean power and the internal/external muscle ratios of these two parameters as measured during isokinetic evaluation of the shoulder. Our study included two complementary analyses. We first studied the influence of wheelchair propulsion by comparing three groups: nonathletic subjects, tennis players and paraplegic wheelchair athletes. We investigated the influence of neurological level by comparing values of peak torque, mean power and internal/external muscles ratio in two subgroups: high paraplegic athletes (HPA/T5–T8) and low paraplegic athletes – poliomyelitics (LPA/T11–L3 and polio). In addition, this analysis determined the influence of dominant and nondominant side on the isokinetic data. It thus tested the hypothesis of a lack of significant difference between dominant and nondominant side in wheelchair athletes using the scapular belt in symmetrical and synchronized activity.

Methods

Subjects

A total of 49 men participated in this study after giving informed written consent. They were assigned to one of three groups. The first group of 12 nonathletic subjects had no athletic activities. Mean age, mean weight and mean height were, respectively, 25.6 years (+3.1), 76.3 kg (+11.7) and 179.2 cm (+8.2). The second group of 15 tennis players had the mean age, mean weight and mean height, respectively, of 25.7 years (+4.7), 70.6 kg (+7.5) and 174.7 cm (+3.9). A third group of 21 wheelchair athletes was composed of tennis players and wheelchair racers. For this group, the mean age, mean weight and mean height were, respectively, 30.8 years (+4.2), 63.9 kg (+8.2) and 173.8 cm (+7.6). Motor and sensory examinations were performed and anthropometric and neurological characteristics were reported (Table 1). We divided this group of 21 subjects into two subgroups based on the International Stoke Mandeville Wheelchair Sports Federation (ISMWSF) classification system. For the group of HPA, ISMWSF class II (T1–T5) and class III (T6–T10), the mean age, weight and height were, respectively, 31.4 years (+4.4), 63.6 kg (+7.9) and 172.7 cm (+8.1). For the group of LPA, ISMWSF class IV and class V (below T10 and assimilate subjects), the mean age, weight and height were, respectively, 30.0 years (+4.1), 64.3 kg (+9.2)

Table 1 Anthropometric and neurological characteristics of two group of wheelchair athletes

	Name	Age (years)	Weight (kg)	Height (cm)	Level	Lesion	Trouble	Size	Sport
High paraplegic athletes	RF	32	56	170	T5	Complete	Spastic	R	Racing
	AT	30	60	171	T5	Complete	Spastic	R	Tennis
	CL	34	56	170	T5	Complete	Spastic	R	Tennis
	RP	35	71	176	T8	Complete	Spastic	L	Tennis
	MP	39	65	169	T8	Complete	Flacid	R	Tennis
	PF	30	65	183	T2	Complete	Spastic	R	Tennis
	GA	37	62	163	T6	Complete	Spastic	R	Racing
	FP	25	47	160	T6	Complete	Spastic	R	Racing
	GL	30	70	170	T7	Complete	Spastic	R	Racing
	SP	32	66	185	T6	Complete	Spastic	R	Racing
	RP	28	75	185	T5	Complete	Flacid	R	Tennis
	TP	25	70	170	T8	Complete	Spastic	R	Racing
	M	31.4	63.6	172.7					
	SD	4.4	7.9	8.1					
Low paraplegic athletes	TP	35	67	175	T11	Complete	Spastic	R	Tennis
	BP	29	70	180	L3	Incomplete	Flacid	R	Tennis
	BS	31	84	184	T11	Complete	Spastic	L	Racing
	BP	25	62	180	L1	Complete	Spastic	L	Racing
	HF	36	54	163	T12	Complete	Spastic	R	Racing
	LA	24	56	165	Polio	0	0	R	Racing
	RP	30	62	180	T12	Complete	Spastic	R	Racing
	BP	32	57	178	T11	Complete	Spastic	R	Racing
	PF	28	67	173	Polio	0	0	R	Racing
	M	30.0	64.3	175.3					
	SD	4.1	9.2	7.2					

and 175.3 cm (+7.2). For the 21 wheelchair athletes, the post-traumatic time was 12.8 years (± 3.7), with 13.8 years (± 2.8) for HPA and 11.7 (± 4.5) for LPA. All of these athletes were without chronic pathology and had no history of surgical intervention, both of which were criteria of exclusion. An informed consent was obtained from each subject.

Protocol

The subjects were seated on a Biodex isokinetic dynamometer (Biodex, Inc., Shirley, NY, USA) and the trunk was secured. Each subject then warmed up for 2 min at a speed of 180°s^{-1} . The evaluation of the internal and external rotator muscles was conducted with 45° abduction of the shoulder in the scapular plane, 30° antepulsion and 130° range of motion. The range of motion in the internal rotation was 45° and the range of external rotation was 85° , based on a reference position of forearm horizontal at 0° . The no-randomly test speeds were 60, 180, and 300°s^{-1} with respectively 5, 5 and 10 repetitions. A duration of 1 min separated each series of movements, although 5 min was needed to prepare for the evaluation of the opposite side and the new warm-up. During the protocol, the peak torque (Nm) and mean power (W) were noted and the internal/external rotation ratios were calculated.

Statistical analysis

Mean values and standard deviations were calculated for all variables. Intergroup comparison of peak torque, mean power, and the internal/external rotation ratio was made using the Kruskal-Wallis test, with significance set at $P < 0.05$. For the comparison of peak torque, mean power and the ratio in the two subgroups of paraplegics, the Wilcoxon test was used. For the comparison of dominant and nondominant side tested in the entire paraplegic group, the Wilcoxon test was used for the peak torque, mean power and ratio, and significance was set at $P < 0.05$.

Results

Influence of lesion and sport

For peak torque at 60°s^{-1} (Table 2a), we observed no significant differences in the strength developed by the three groups of subjects in internal and external rotations for both side. At 180 and 300°s^{-1} , only the internal rotator showed significant differences between the three groups ($0.02 < P < 0.05$). For the internal/external muscle ratio for both sides, we observed significantly higher values in the wheelchair athlete group ($0.001 < P < 0.05$), except for the ratio at 60°s^{-1} . The comparison of mean power (Table 2b) in the three groups at the three speeds on both the dominant and nondominant sides showed no significant differences. For the ratios, we observed significantly different values among groups on the nondominant side at 180°s^{-1} ($P < 0.04$) and on the dominant size at 300°s^{-1} ($P < 0.02$).

Table 2 Means and SDs of (a) peak torque (Nm), (b) mean power (W) and internal/external rotator muscle ratios (R) of peak torque and mean power for the three group of subjects at the three test speeds (60, 180, 300°s^{-1})

		60DIR			60NIR			180DIR			180NIR			300DIR			300NIR		
		M	SD	R	M	SD	R	M	SD	R	M	SD	R	M	SD	R	M	SD	R
(a) Peak torque (Nm)	Nonathletic	56.42	14.21	1.42	39.83	9.69	0.20	56.20	14.33	0.20	42.71	8.22	0.17	51.49	11.63	0.17	42.71	8.22	0.17
	Tennis	57.37	11.45	1.48	39.02	5.66	0.26	54.05	8.80	0.25	40.11	7.48	0.25	50.57	8.96	0.25	40.11	7.48	0.25
	Wheelchair	63.32	11.47	1.71	37.49	7.21	0.29	64.9	14.46	0.27	43.63	8.8	0.27	55.48	15.47	0.27	43.63	8.8	0.27
(b) Mean Power (W)	Nonathletic	42.71	11.18	1.45	29.54	6.88	0.19	39.89	12.80	0.20	31.33	7.49	0.20	89.29	26.48	0.20	31.33	7.49	0.20
	Tennis	45.15	15.48	1.38	33.41	15.02	0.23	41.26	7.38	0.19	31.17	7.74	0.19	94.26	21.86	0.19	31.17	7.74	0.19
	Wheelchair	45.99	13.48	1.67	28.40	7.51	0.43	48.59	14.42	0.26	33.27	7.67	0.26	101.1	39.2	0.26	33.27	7.67	0.26
Sig		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DIR: dominant side in internal rotation; DER: dominant side in external rotation; NIR: nondominant side in internal rotation; NER: nondominant side in external rotation; R: ratio

Influence of neurological level

For peak torque (Figure 1a), we observed significantly higher values in LPA in internal and external rotations on the dominant side at the three test speeds ($0.01 < P < 0.04$). Except for 60NIR and 180NIR, the comparison of peak torque on the nondominant side showed significant differences between the two groups in external rotation at 60°s^{-1} ($P < 0.05$) and 180°s^{-1} ($P < 0.05$) and at 300°s^{-1} in internal rotation ($P < 0.02$) and external rotation ($P < 0.01$). For mean power (Figure 1b), the comparison of the two groups at the three speeds and both sides showed significantly higher values of the external rotator muscles in LPA ($0.01 < P < 0.04$). For the internal rotator muscles at 60°s^{-1} , no significant difference was noted between the two groups. At 180°s^{-1} , only the internal rotator muscles on the nondominant side revealed significant differences between the two groups ($P < 0.03$). At 300°s^{-1} , the LPA group presented significantly higher values on the dominant side ($P < 0.03$) and the nondominant side ($P < 0.02$).

For the peak torque ratios (Table 3a) and mean power ratios (Table 3b) in the six test conditions, comparison showed no significant differences.

Influence of side in wheelchair athletes

Comparison of the peak torque of the internal rotator muscles in all test conditions revealed no significant differences (Table 4a). For the external rotator muscles, we observed significantly higher values on the nondominant side at 60 and 180°s^{-1} ($P < 0.02$). For mean power (Table 4b), we observed similar results, with

Figure 1 (a) Means of peak torque (Nm) and (b) mean power (W) in the HPA and LPA at the three test speeds of 60, 180 and 300°s^{-1} (DIR: dominant side in internal rotation; DER: dominant side in external rotation; NIR: nondominant side in internal rotation; NER: nondominant side in external rotation)

Table 3 Means and SDs of the internal/external muscle ratios of (a) peak torque and (b) mean power in HPA and LPA

	R60D	R60N	R180D	R180N	R300D	R300N
<i>(a) Peak torque (Nm)</i>						
High paraplegic						
M	1.8	1.6	1.7	1.6	1.6	1.6
SD	0.3	0.3	0.3	0.1	0.3	0.2
Low paraplegic						
M	1.7	1.4	1.6	1.4	1.6	1.5
SD	0.3	0.2	0.3	0.2	0.3	0.3
Significance	NS	NS	NS	NS	NS	NS
<i>(b) Mean power (W)</i>						
High paraplegic						
M	1.7	1.5	1.7	1.6	1.8	1.6
SD	0.5	0.2	0.4	0.2	0.3	0.2
Low paraplegic						
M	1.6	1.4	1.7	1.4	1.7	1.5
SD	0.4	0.3	0.4	0.3	0.4	0.4
Significance	NS	NS	NS	NS	NS	NS

R60D: ratio of dominant side at 60°s^{-1} ; R60N: ratio of nondominant side at 60°s^{-1} ; R180: ratio at 180°s^{-1} ; R300: ratio at 300°s^{-1}

Table 4 Means and SDs of (a) peak torque (N m) and (b) mean power (W) of the group of 21 wheelchair athletes at the three test speeds of 60, 180, and 300° s⁻¹.

<i>(a) Peak torque (N m)</i>						
	60DIR	60DER	180DIR	180DER	300DIR	300DER
M	63.20	37.50	55.50	33.70	56.70	34.60
SD	11.5	7.2	15.5	7.9	14.2	7.1
	60NIR	60NER	180NIR	180NER	300NIR	300NER
M	64.90	43.60	56.40	37.70	55.20	37.10
SD	14.5	8.8	12.0	8.0	12.2	8.8
Significance	NS	0.02	NS	0.02	NS	NS
<i>(b) Mean power (W)</i>						
	60DIR	60DER	180DIR	180DER	300DIR	300DER
M	46.00	28.20	101.10	58.90	118.50	67.30
SD	13.5	7.5	39.2	19.9	44.1	21.0
	60NIR	60NER	180NIR	180NER	300NIR	300NER
M	48.7	33.20	102.1	68.3	113.90	76.1
SD	14.4	7.7	31.4	20.0	38.4	24.5
Significance	NS	0.01	NS	0.02	NS	NS

DIR: dominant side in internal rotation; DER: dominant side in external rotation; NIR: non-dominant side in internal rotation; NER: non-dominant side in external rotation

Figure 2 (a) Mean values of peak torque ratios and (b) mean power ratios in the group of 21 wheelchair athletes (60R: ratio of dominant side at 60 s⁻¹; 180R: ratio at 180 s⁻¹; 300R: ratio at 300 s⁻¹; Dom: test of dominant side; Ndom: test of nondominant side)

significantly higher values for the external rotator muscles on the nondominant side at 60° s⁻¹ ($P < 0.01$) and 180° s⁻¹ ($P < 0.02$).

Analysis of the mean values of peak torque and mean power revealed systematically higher values for the internal/external rotator muscle ratios measured on the dominant side. For peak torque, only comparison of the ratio at 60° s⁻¹ showed a significant difference between the two sides ($P < 0.02$) (Figure 2a). In contrast, for mean power, the comparison of ratios at all three speeds revealed significant differences ($0.02 < P < 0.03$) (Figure 2b).

Discussion

The analysis of peak torque values showed no significant differences between the three groups of subjects without characteristic signs of subacromial conflict, except at 300° s⁻¹ on the nondominant side in internal rotation. Nevertheless, despite no statistical difference, it is worth noting that in all conditions of speed and side tested, the paraplegic athletes systematically developed higher values of peak torque in internal rotation. Although both the anterior and posterior muscular chains were solicited in the paraplegic subjects, it seems that wheelchair propulsion favors the development of internal rotators. In fact, in all tests of both the dominant and nondominant sides, the paraplegic athletes presented higher mean values for the external rotators in only a single test condition, at 60° s⁻¹ on the nondominant side. An interesting question is whether the neurological level of lesion, which will be discussed below, influences the development of the specific muscles participating in wheelchair propulsion.^{12,13}

Regarding the agonist/antagonist ratios, in five of the six test conditions the paraplegic athletes developed

significantly higher values compared with the two other groups. The higher values of the internal rotator muscles in the paraplegics explain our finding of ratios close to 1.70 on the dominant side and close to 1.50 on the nondominant side. These values were lower in the paraplegics explain our finding of ratios close to 1.70 on the dominant side and close to 1.50 on the nondominant side. These values were lower in the two other groups, who showed relatively similar values between 1.17 and 1.42 for the nonathletic subjects and between 1.34 and 1.51 for the tennis players. These latter values were in line with the normative data determined between 1.30 and 1.50.^{14,15} The values near 1.50 of the tennis players might be surprising, as these athletes intensively solicit the scapular belt and the upper body musculature. In addition to the serve and smash, which develop the internal rotators, a wide variety of racket positions and swings are used by experienced players that may favor the development of the external rotators. Electromyographic analysis of shoulder during athletic activity have shown complex sequences of muscle activity during the different stage of the movement.^{16–19} The values of our group of 21 wheelchair athletes were significantly higher than the theoretical definition of muscular balance in rotator muscles. They were also higher than those of the group studied in our first investigation.²⁰ The group of 21 paraplegics athletes in the present study was equally divided into tennis players and wheelchair racers. As has been done in some studies, it would be interesting to isolate the neurological data and to determine the influence of sport discipline to test the validity of the hypothesis of significant development of internal rotators in racer athletes. As defined by different authors, it seems that internal rotators participation was in relation and was greater in the athletes with higher performance levels.^{21,22} Each of these two characteristics or their association could explain the muscular imbalance seen in our group of 21 wheelchair athletes.

The interpretation of the peak torque values was supported by the analysis of mean power. In fact, although only the ratios at 180°s^{-1} on the nondominant side and at 300°s^{-1} showed significant differences among the three group of subjects, we observed higher values of internal rotators for the mean power of the paraplegic athletes, for the three speeds and two sides tested. These values favor an overall ratio between 1.30 and 1.50 for the nonathletic subjects and tennis players and between 1.46 and 1.75 for the wheelchair athletes.

The aim of our second analysis was to compare 12 HPA with nine LPA to define the effect of neurological level on peak torque, mean power and muscular balance. We first noted higher values of torque and power for the internal and external muscles of LPA. Closer study, however, revealed similarity in the significant differences noted between the internal and external values in both groups. In fact, in all test conditions (three speeds and two sides), peak torque and mean power values of the external rotators were significantly higher in LPA. In these low-level paraplegics, peak torque of the internal rotators was

systematically higher on the dominant side in comparison with the nondominant side, if only at 300°s^{-1} . The mean power of internal rotators was only slightly discriminative since significant differences between the two groups were found only at 180 and 300°s^{-1} on the nondominant side and at 300°s^{-1} on the dominant side. It thus seems that neurological level of lesion does not systematically influence the development of internal rotator muscles. In contrast, the participation of the external rotators appears strongly correlated to neurological level. The LPA peak torque and mean power values for the external rotators indicate that thoracic–lumbar-level paraplegics depend on these muscles during propulsion and, consequently, develop higher contractile properties in them.

Analysis of the internal rotator/external rotator ratios provides further insight into the influence of neurological level on the muscular adaptations of individuals with spinal cord injury. In fact, we may hypothesize that HPA have a greater imbalance in relationship with the preferential development of flexor, internal rotator, and adductor muscles, which increases the likelihood of chronic muscular imbalance. No studies have shown a correlation between muscular imbalance and shoulder pathologies such as impingement syndromes or instability. Nevertheless, in their assessments of wheelchair athletes, different authors have emphasized the possible role of muscular imbalance in the development of pathology.^{7,11,23,24} For individuals with spinal cord injury, clinical signs of overuse and pathology are most often noted in the cervical spine, scapulohumeral joint muscle–joint complex of the upper body.^{6,8,25,26}

It seems difficult to conclude with respect to the influence of neurological level based on the muscular balance values in the two groups of paraplegics. In fact, no statistical differences were observed between the two groups for any test condition. Agonist/antagonist ratios are individual indicators that are relevant to rehabilitation, but it would be an error to try to prove a relationship with cross-sectional studies when, in fact, longitudinal investigations are called for. Despite the absence of significant difference in the ratios of the two groups and the difficulty of interpreting the possible relationships between the values of muscular imbalance and muscle–joint overuse, it is important to emphasize two points. The first concerns the role of transfers in wheelchair use. Transfers develop muscle both isometrically in the scapular muscles, such as Latissimus dorsi, Pectoralis major, Teres major and Infraspinatus muscles. This type of work mainly develops the adductors, and it appears that, despite the constraints of compression on the subacromial space, muscular synergies reduce the potential for the impingement of the rotator cuff.²⁷ Nevertheless, it is important not to underestimate this aspect of wheelchair locomotion and to insist on education and training in transfers in order to prevent premature joint degeneration. The second point is that, despite the mean values, certain individual values of the athletes require particular attention. Muscle balance seems to have an important protective role for

musculoarticular structures undergoing strenuous physical demands.^{7,11,24} These values are indications that a program to improve muscle balance and joint flexibility could prevent chronic injury. A long-term intraindividual follow-up would confirm this hypothesis and pinpoint the relationship between the evolution of muscular characteristics and the prevalence of musculoarticular dysfunction.

The comparison of peak torque and mean power values showed the same type of differences. We observed significantly higher values for the external rotators on the nondominant side in comparison with the dominant at the speeds of 60 and 180° s⁻¹ (0.01 < *P* < 0.02). For all tests in internal rotation, as well as at 300° s⁻¹ in external rotation, there were no significant differences. In contrast, the mean values showed that, except at 300° s⁻¹ in internal rotation, the paraplegics showed higher values of peak torque and mean power on the nondominant side (Figure 2a). Ratio variations as a function of side have been widely studied but no consensus has been reached. In athletic populations, different studies have demonstrated higher values for the dominant side,^{28,29} an absence of significant difference between the two sides,^{30,31} and higher values on the dominant side as a function of test speed³² or the mode of muscle contraction.³³ For our group, it seems difficult to explain the results. Why did the paraplegics develop lower force and lower power on the nondominant side? Is this a specificity of wheelchair propulsion? The higher values on the dominant side may be related to the pain and injury that affect this side, eventually leading to underdeveloped contractile properties. This interpretation is hypothetical; however, it would be interesting to test it in relationship with the constraints generated by transfers and the injuries that affect specifically one joint. The comparison of ratios (Figure 2b) showed higher values on the dominant side. These differences were significant for mean power at the three test speeds (0.02 < *P* < 0.03), whereas they were noted only at the slowest speed for peak torque (*P* < 0.02). As mentioned above, the ratios measured on the nondominant side were close to 1.50, a value frequently noted in athletic populations. In contrast, the values of the dominant side were between 1.65 and 1.75 for peak torque and mean power and were significantly different for two-thirds of the test speeds. Our study thus raises important questions about ratios that are far from the normative values and the follow-up that should be implemented to monitor them.

Conclusion

This study showed that in two-thirds of the cases the values of the external rotators were significantly higher than those of the internal rotators on the nondominant side for peak torque and mean power. The ratios on the dominant side were systematically higher than on the nondominant side, with significant differences in two-thirds of the cases. Although we do not propose an association of these two findings, the question

certainly can be raised: are these values related and, if so, how can they add to our understanding of muscle-joint adaptations?

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