ORIGINAL ARTICLE

Assessment of agonist–antagonist shoulder torque ratios in individuals with paraplegia: a new interpretative approach

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Study Design: Cross-sectional study.

Objective: To evaluate isokinetic shoulder flexor–extensor (F/E) and abductor–adductor (Ab/Ad) torque ratios in individuals with paraplegia using a new interpretative approach. We proposed to study torque ratios according to joint angle sections (15° angle subgroups) over a selected range of motion.

Setting: Pathokinesiology Laboratory, Montreal, Canada.

Method: Sixteen individuals with complete motor paraplegia, without shoulder pain or impairment, were included in this study. After a preloading period of 1 s, maximum isokinetic concentric contractions of all muscle groups were completed at 30, 60 and 120° s⁻¹ over the entire tested ranges of motion (70 to –35° for the flexion–extension and 15 to 60° for the abduction–adduction). After the continuous torque curves were rebuilt, the mean F/E and Ab/Ad torque ratios were calculated and analyzed every 15°.

Results: A significant modification of the F/E ($F=66.3$; $P<0.001$) and Ab/Ad ($F=100.6$; $P<0.001$) torque ratios was observed according to the 15° angle subgroup evaluated. More precisely, a progressive decline of both the F/E and Ab/Ad ratios was noted as the shoulder flexion or abduction progressed. Angular velocity did not have any influence on torque ratio values.

Conclusion: Angle subgroup torque ratio analysis leads to a better estimation of the balance between the agonist and antagonist muscle groups than does traditional peak torque ratio analysis. In individuals with paraplegia, this precise estimation of torque ratios may lead to the development of specific shoulder strengthening programs to prevent muscle imbalance and its consequences.

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Introduction

The upper extremities (U/E) become the propulsive segments for manual wheelchair mobility among individuals with spinal cord injury (SCI). A consequence of this functional adaptation is the increased risk of developing secondary musculoskeletal impairments, most likely affecting the shoulder joints.^{1–4} Shoulder strength imbalance between the agonist and antagonist muscle groups may play a key role in the development of secondary impairments among individuals with SCI.^{5,6}

Calculating isokinetic shoulder torque ratios is a well-accepted method for highlighting the imbalance between agonist and antagonist muscle groups. However, no consensus

exists as to the torque assessment methods and approaches used to report torque ratios. Usually, ratios are evaluated using the isokinetic peak torque of the agonist muscle compared to that of the antagonist muscle, in concentric or eccentric mode, without reference to the angles (segment positions) where these peak torques are obtained.⁷ Most likely, peak torques do not occur at the same angle for the agonist and antagonist muscle groups irrespective of the mode of contraction (eccentric or concentric). This suggests that a peak torque ratio may not adequately describe the dynamic agonist–antagonist muscle balance of an articulation.

A complete torque ratio study along a useful or a selected range of motion could allow for better estimation of dynamic muscle balance. Specifically for the shoulder, this could allow rehabilitation specialists to gain a better insight into the U/E strength-generating capability among individuals with SCI and locate potential muscle imbalances

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affecting specific portions of the tested range of motion. In addition, it may improve the specificity and precision of a resistance strength training protocol intended for these patients.

The aim of the present study was to evaluate the isokinetic flexor–extensor and abductor–adductor torque ratios of the dominant shoulder in individuals with complete motor paraplegia using a new interpretative approach. This new interpretative approach proposed to study torque ratios between agonist and antagonist muscle groups according to specific joint angle sections over a selected range of motion. The hypothesis was that this method may provide better insight into shoulder muscle balance compared to peak torque ratio analysis that is frequently used.

Methods

Participants

A convenience sample of 16 males (volunteers) with severe sensory–motor impairments at their trunk and lower extremities secondary to spinal cord lesion resulting from a traumatic injury participated in this study (Table 1). All participants were at least 2-year post-SCI, right-hand dominant, independently propel their manual wheelchair during a minimum of 60 min per day, independently transfer to and from their wheelchair around 19 times daily and reported an activity tolerance of at least 60 min when frequent rest periods are offered. None of the participants had the ability to ambulate despite the use of technical or technological aids. Subjective assessment and objective clinical examination (passive and active movements, resisted static movements, clinical diagnostic tests and palpation) confirmed that none of the participants had previously experienced or experienced at the time of testing any sign or symptom of musculoskeletal impairment affecting the trunk or upper extremities, or suffered from any other condition that might alter their U/E strength-generating capability. Ethical

approval was obtained from the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal. All participants reviewed and signed an informed consent form before entering the study.

Dynamometric assessment

An isokinetic dynamometric assessment was completed using a Biodex system to quantify maximum voluntary concentric strength of the right shoulder flexors, extensors, abductors and adductors. All participants were positioned on the chair of the Biodex system at 90° knee flexion and 70° hip flexion since the backrest was reclined by 20°. An optimal level of external stabilization was provided to ensure that participants exerted maximum effort. For all movements investigated, the dynamometer was set to isokinetic passive mode and participants were asked to concentrically contract as forcefully as possible in the desired direction. The passive mode was selected to ensure that the apparatus and body segment would move throughout the entire tested range of motion. A pre-loading period of 1 s, which allowed the participants to place their series elastic components under tension and build up their strength, ascertains the production of maximum strength early during the movement.⁸ For each movement tested, two trials were performed for each muscle group. A resting period of 30 s was given between the contractions and a two-min rest period was allowed when direction of movement was changed.

For the shoulder flexion and extension movements, participants grasped the handgrip with their forearm in a neutral position with their elbow in slight flexion (35°). Joint torques in each direction were measured between 70° shoulder flexion and –35° shoulder extension. For the shoulder abduction and adduction movements, participants also grasped the handgrip with their forearm in a neutral position with their elbow in slight flexion (35°). Joint torques in each direction were measured between 15 and 60° of shoulder abduction. For all movements tested,

Table 1 Demographics and clinical characteristics of participants

Subject	Age (year)	Height (m)	Weight (Kg)	Time since injury (year)	ASIA motor (/100)	ASIA sensory (/224)	Impairment scale	Level of lesion
1	31.8	1.68	75.0	2.8	50	88	A	T4
2	49.3	1.78	86.1	4.8	50	88	A	T4
3	33.8	1.83	80.7	2.4	50	92	A	T4
4	38.1	1.73	51.3	6.9	50	92	A	T4
5	56.3	1.70	100.5	6.3	67	148	C	T4
6	41.6	1.72	93.6	3.2	50	96	A	T5
7	30.2	1.73	84.6	2.4	50	96	A	T5
8	27.5	1.75	64.4	3.6	50	100	A	T5
9	54.1	1.70	63.8	31.7	50	104	A	T6
10	34.5	1.72	61.0	6.8	50	110	B	T6
11	48.7	1.85	104.6	6.4	50	111	A	T6
12	39.0	1.85	105.2	5.3	50	112	A	T7
13	37.5	1.58	63.3	3.5	50	128	A	T9
14	59.3	1.78	98.6	3.0	50	155	B	T10
15	44.8	1.73	105.3	5.0	50	144	A	T11
16	51.7	1.88	88.7	33.5	50	144	A	T11
Mean	42.4	1.75	82.9	8.0	51.1	113.0		
s.d.	9.9	0.08	17.9	9.7	4.3	23.3		

maximum isokinetic concentric contractions were completed at 30, 60 and 120° s⁻¹. These movement amplitudes and angular velocities for the shoulder tests were selected to replicate shoulder kinematic parameters frequently observed during wheelchair propulsion and sitting pivot transfers among this population (D Gagnon *et al.* 2007, under review). A custom-made Labview program allowed real-time observation and recording of the torque, angle and velocity of movements of all tests performed.

It should be noted that the selection of the muscle groups investigated in the current study, along with their range of motion and angular velocity parameters, were determined from the results of a kinematic assessment targeting sitting pivot transfers performed by individuals with complete thoracic SCI (D Gagnon 2007, under review). Thus shoulder rotator muscles were not assessed in this study.

Outcome measures

The torque curves were generated for all movements and velocities investigated using gravity-corrected torque data at each angle of movement over the entire tested range. From these data, the shoulder flexion–extension (F/E) and abduction–adduction (Ab/Ad) torque ratio curves were calculated. Then, the torque curves and torque ratio curves were each stratified into seven 15° angle subgroups for the flexion–extension movement and three 15° angle subgroups for the abduction–adduction movements, respectively. For each 15° angle subgroup, mean F/E and Ab/Ad torques and mean torque ratios were calculated. For each movement, the 15° angle subgroup in which the highest torque value was measured was named the reference angle subgroup. In addition, peak torque and peak torque ratios (F/E and Ab/Ad peak torque ratios) were also assessed independently of joint position.

Statistical analysis

After verifying the normality of the distribution for each 15° angle subgroup generated for all movements studied using the Kolmogorov–Smirnov test for each angular velocity, Pearson product–moment coefficients of correlation were used to determine the association between the reference angle subgroup torque and the other angle subgroup torque values for each movement. Thereafter, two-way repeated-measures analysis of variance were used to determine the effects of joint position (15° angle subgroups) and angular velocity (30, 60 and 120° s⁻¹) on the shoulder F/E and Ab/Ad torque ratios. In the absence of interaction (joint position X angular velocity), main effects were analyzed to determine the influence of the joint position or angular velocity. All statistical analyses were performed using SPSS (version 13.0, Chicago IL, USA).

Results

Torque curves

Shoulder flexion–extension and abduction–adduction mean torque curves at the three angular velocities are shown in Figures 1a and b, respectively. Overall, similar torque curves

were found across the three angular velocities for shoulder flexion–extension and abduction–adduction. Typically, shoulder flexion and extension torque as well as abduction and adduction torque were the highest at the start of the movement amplitude tested and progressively decreased thereafter. The cross point, defined as the point where agonist and antagonist muscle torques are equal, always occurred within the fifth 15° angle subgroup (26–40°) for the shoulder flexion–extension movements and within the first 15° angle subgroup (15–29°) for the shoulder abduction–adduction movements, irrespective of angular velocity. Note that the mean (± 1 s.d.) peak torque for each muscle group tested is presented in Table 2.

Correlations between angle subgroup mean torques

The intercorrelation between the reference angle subgroup's mean torque values and the other angle subgroup's mean torque values are presented in Tables 3 and 4. For each muscle group, the correlation diminished when the angle subgroup considered for analysis moved away from the reference subgroup. For the extension movement, no significant correlation was found between the mean torque measured within the reference angle subgroup and the last two subgroups at 60° s⁻¹. A similar finding was also found when tested at 120° s⁻¹ between the reference angle subgroup and the last subgroup only. For the correlations between the peak torque and the angle subgroup's mean torque, they are also presented in Tables 3 and 4. These correlations progressively decline as the angle subgroups move away from the peak torque.

Angle subgroup torque ratios

Mean (± 1 s.d.) shoulder flexor–extensor and abductor–adductor torque ratios at the three angular velocities calculated every 15° over the entire tested range (angle subgroups) are shown in Figures 2a and b. The mean peak torque ratio for each angular velocity is also illustrated for comparison purposes in these same figures. According to the angular velocities, mean peak torque ratios ranged from 1.07 to 1.10 and from 0.87 to 0.96 for F/E and Ab/Ad, respectively. Only joint positions (15° angle subgroups) were found to significantly influence shoulder F/E and Ab/Ad torque ratio values, independently of velocity, which had no effect. More precisely, a progressive decline of the shoulder F/E torque ratio was observed as the shoulder progressed into flexion, whereas the Ab/Ad torque ratio was found to decrease as the shoulder abduction increased.

Discussion

A detailed assessment of agonist–antagonist muscle balance, especially around the shoulder joints, is of key relevance among individuals with SCI given the fact that the level of lesion and the functional status of the U/Es may change muscle strength. In this population, agonist–antagonist muscle strength imbalances have been linked to an increased risk of developing secondary musculoskeletal impairments affecting the shoulder joints.⁵ Such impairments could not

Figure 1 (a) Shoulder flexion and extension mean torque (Nm) over the entire tested range (angle in degrees) at the three tested velocities (30, 60 and 120° s⁻¹). Broken arrow indicates the angle value where flexion and extension torques are equal. (b) Shoulder abduction and adduction mean torque (Nm) over the entire tested range (angle in degrees) at the three tested velocities (30, 60 and 120° s⁻¹). Broken arrow indicates the angle value where abduction and adduction torques are equal.

Table 2 Mean peak torque values (s.d.) for each tested movement (in Nm)

Angular velocity	Flexion	Extension	Abduction	Adduction
30° s ⁻¹	87.2 (24.9)	79.7 (20.1)	74.2 (19.0)	86.8 (21.7)
60° s ⁻¹	86.2 (25.8)	79.3 (20.1)	73.9 (19.1)	81.3 (20.9)
120° s ⁻¹	79.9 (25.5)	74.9 (19.3)	73.0 (19.9)	76.4 (17.8)

only jeopardize the ability to perform functional activities,⁹ but also the level of social participation among individuals with SCI.

Limits of agonist–antagonist peak torque ratios

The F/E and Ab/Ad peak torque ratios calculated in the current study are in concordance with those previously reported among healthy individuals.^{10,11} However, the current peak torque ratios are about 25% lower than those recently reported for individuals with SCI.¹² This discrepancy may be partly explained by methodological differences affecting shoulder strength-generating capability, especially the use or nonuse of a pre-loading period.

Although the agonist–antagonist peak torque ratio provides an estimate of the agonist–antagonist muscle strength relationship, the use of the agonist–antagonist peak torque ratio appears inadequate, at first, to conclude on the

dynamic agonist–antagonist muscle strength balance observed over the entire range of movement possible at a joint. Such an approach would only be adequate in the presence of a perfect correlation between the agonist and antagonist muscles over the entire tested range of motion, which is not expected in clinical practice. The dynamic muscle balance over the functional range of motion is known to constantly change as the joint angle is modified.¹³ In addition, at the shoulder, the joint angle where the peak torque is generated has been found to be difficult to reproduce between tests.^{14,15}

Interests of the angle subgroup agonist–antagonist torque ratios

A new interpretative approach of the torque ratios between shoulder agonist and antagonist muscle groups is proposed in the current study. In addition to the F/E and Ab/Ad peak torque ratios, the F/E and Ab/Ad torque ratios were evaluated over the entire selected range of motion to refine their interpretation. To facilitate the interpretation, the F/E and Ab/Ad torque ratios were averaged every 15 degrees, which allowed for additional analysis compared to the approach that only focused on peak values. The proposed subgroup torque ratio analysis was primarily justified by the fact that the agonist and antagonist peak torques occurred at different angles and because a high peak torque does not necessarily mean that all torques produced within the entire range of

Table 3 Inter-correlations between angle subgroup mean torque values and correlations between angle subgroup mean torque values and peak torque for shoulder flexors and extensors

	Subgroup mean torque values			Peak torque values		
	Flex (30° s ⁻¹) -35 to -20°	Flex (60° s ⁻¹) -35 to -20°	Flex (120° s ⁻¹) -35 to -20°	Flex PT (30° s ⁻¹)	Flex PT (60° s ⁻¹)	Flex PT (120° s ⁻¹)
Flex ^a -35 to -20°	1	1	1	0.99**	0.99**	0.99**
Flex -19 to -5°	0.95**	0.97**	0.97**	0.93**	0.94**	0.92**
Flex -4 to 10°	0.87**	0.91**	0.96**	0.84**	0.87**	0.88**
Flex 11-25°	0.83**	0.89**	0.94**	0.80**	0.84**	0.85**
Flex 26-40°	0.75**	0.90**	0.92**	0.74**	0.85**	0.82**
Flex 41-55°	0.72**	0.87**	0.89**	0.69**	0.82**	0.76**
Flex 56-70°	0.58*	0.79**	0.77**	0.54*	0.74**	0.70**
	Ext (30° s ⁻¹) 56-70°	Ext (60° s ⁻¹) 56-70°	Ext (120° s ⁻¹) 56-70°	Ext PT (30° s ⁻¹)	Ext PT (60° s ⁻¹)	Ext PT (120° s ⁻¹)
Ext ^a -35 to -20°	0.61*	0.49	0.47	0.59*	0.59*	0.49
Ext -19 to -5°	0.61*	0.45	0.51*	0.66*	0.65**	0.53*
Ext -4 to 10°	0.60*	0.51*	0.64**	0.78**	0.76**	0.64*
Ext 11-25°	0.73**	0.69**	0.73**	0.90**	0.84**	0.72**
Ext 26-40°	0.89**	0.90**	0.86**	0.94**	0.88**	0.79**
Ext 41-55°	0.94**	0.97**	0.95**	0.97**	0.93**	0.90**
Ext 56-70°	1	1	1	0.99**	0.99**	0.98**

Abbreviations: Flex, flexors; Ext, extensors; PT, peak torque.

* $P < 0.05$.** $P < 0.01$.^aTested at corresponding column velocity (30 or 60 or 120° s⁻¹).**Table 4** Inter-correlations between angle subgroup mean torque values and correlations between angle subgroup mean torque values and peak torque for shoulder abductors and adductors

	Subgroup mean torque values			Peak torque values		
	Abd (30° s ⁻¹) 15-29°	Abd (60° s ⁻¹) 15-29°	Abd (120° s ⁻¹) 15-29°	Abd PT (30° s ⁻¹)	Abd PT (60° s ⁻¹)	Abd PT (120° s ⁻¹)
Abd ^a 15-29°	1	1	1	0.98**	0.97**	0.97*
Abd 30-44°	0.92**	0.92**	0.93**	0.85**	0.83**	0.83**
Abd 45-60°	0.82**	0.81**	0.91**	0.74**	0.69**	0.81**
	Add (30° s ⁻¹) 45-60°	Add (60° s ⁻¹) 45-60°	Add (120° s ⁻¹) 45-60°	Add PT (30° s ⁻¹)	Add PT (60° s ⁻¹)	Add PT (120° s ⁻¹)
Add ^a 15-29°	0.89**	0.87**	0.84**	0.70**	0.71**	0.70**
Add 30-44°	0.99**	0.98**	0.95**	0.73**	0.74**	0.75**
Add 45-60°	1	1	1	0.89**	0.90**	0.90**

Abbreviations: Abd, abductors; Add, adductors; PT, peak torque.

* $P < 0.05$.** $P < 0.01$.^aTested at corresponding column velocity (30 or 60 or 120° s⁻¹).

motion are also high. Our results provide some arguments in favor of this hypothesis. Thus, the level of association between each 15° angle subgroup torque diminished as the importance of the distance between angular sections tested increased for all muscle groups explored. Thus, the strongest subjects in the reference angle subgroup, where the peak torque was systematically observed, were not necessarily the strongest over the entire range of motion. This means that the strength ratio will also be affected.

The angle subgroup torque ratios analysis showed that the agonist-antagonist torque ratios were not constant and were significantly different according to the tested 15° angular

subgroups. A constant decrease of the F/E and Ab/Ad torque ratios was observed between the onset and the end of the selected range of motion (that is, 70 to -35° for flexion-extension and 15-60° for abduction-adduction, respectively) as the strength of the agonist muscles progressively decreased, whereas the strength of the antagonist muscles increased. This further supports the need to consider joint position (angle) when assessing strength ratios.

Isolated agonist and antagonist torque curve analyses should not be neglected when reporting strength ratios. Indeed, it shows the modifications of the agonist and antagonist strength values according to the length-tension

Figure 2 (a) Angle subgroup flexor–extensor torque ratios and peak torque ratios. (b) Angle subgroup abductor–adductor torque ratios and peak torque ratios.

relationship. In addition, these torque curves confirm that the peak torque ratios are systematically calculated from noncorresponding angle values, which are usually recorded at both ends of the range of motion.

For torque ratios to become more representative of the agonist and antagonist demands found during functional activities, some authors proposed to calculate ratios in reference to the mode of contraction in which the muscle is usually solicited, that is, in concentric or eccentric mode. For the U/Es, this method has been proposed, to better evaluate the relationship between shoulder rotators.^{16–18} Ng *et al.*¹⁹ and more recently Yildiz *et al.*¹⁸ used this eccentric–concentric approach to report torque ratios over an angular section (terminal range) where the antagonist muscles played a decelerator role (eccentric contractions). For these authors, this method is well adapted for investigating shoulder dynamic stability, especially among athletes performing overhead tasks (that is, throwing). This method of estimating muscle ratios (eccentric antagonist/concentric agonist) could be applied to evaluating angle subgroup torque ratios, which we proposed in our study, once biomechanical studies have confirmed the type of contraction required during specific tasks. Further studies are necessary to confirm the interest of this procedure. Another application of the angle subgroup torque ratio evaluation may be to properly evaluate the U/E muscle balance in incomplete tetraplegic subjects, particularly before and after functional U/E surgical reconstruction and muscle–tendon transfers. Norms in healthy subjects are also warranted to be able to judge strength ratio changes in individuals with impairments and disabilities.

Angle subgroup torque ratio analysis leads to a better estimation of the balance or imbalance between the agonist and antagonist muscle groups over a functional or selected range of motion than does traditional peak torque ratio analysis. This approach can be used to precisely assess shoulder agonist–antagonist strength balance, especially among individuals with SCI. Their agonist–antagonist

muscle balance may be altered by shoulder muscle paralysis, reduced proximal stability, new U/E functional status as well as secondary U/E musculoskeletal impairments, which are common in this population. Angle subgroup torque ratios analysis represents a promising approach for developing specific shoulder–strengthening programs for individuals with SCI, particularly during the initial rehabilitation period. In fact, this approach provides an opportunity to precisely identify angular sections presenting an imbalance between agonist and antagonist muscle groups.

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