

Shoulder abduction torque steadiness is preserved in subacromial impingement syndrome

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Abstract This study compared peak torque and torque steadiness during isometric abduction in subjects with subacromial impingement syndrome (SIS) and those with no upper limb disorders. The SIS group consisted of 27 subjects (33.48 ± 9.94 years) with unilateral SIS. The control group consisted of 23 healthy and active subjects (32.26 ± 9.04 years). Peak torque and torque steadiness were measured during isometric abduction (80° in the scapular plane) of the shoulder. Standard deviation, coefficient of variation, stability time, median frequency, and relative power were measured from the steadiness trials. There were neither significant interactions between group and side ($P > 0.05$), nor were there significant main effects of group and side ($P > 0.05$) for all variables analyzed. The results of this study showed that steadiness is preserved by SIS during isometric abduction of the shoulder.

Keywords Fluctuation · Rotator cuff · Shoulder pain · Rehabilitation

Introduction

Steadiness refers to the ability to perform muscle contractions with minimum fluctuations while matching a given force/torque level (Bandholm et al. 2006). During a voluntary muscle contraction, the output of motor units results in muscle force/torque that fluctuates (Enoka et al. 2003; Tracy et al. 2007). The fluctuations are attributable to two mechanisms: one related to the mechanical summation of motor unit forces and another involving the pattern of output from the motorneuron pool (Enoka et al. 2003; Taylor et al. 2003). These fluctuations impair the ability of an individual to exert a desired force or torque (Bandholm et al. 2008).

Recently, reduced steadiness during concentric abduction, but not during isometric abduction, was found in subjects with subacromial impingement syndrome (SIS, Bandholm et al. 2006). The authors related this finding to the fact that all subjects were regularly engaged in upper extremity strength training. However, they observed that experimental pain reduced the steadiness of isometric shoulder abduction in healthy subjects (Bandholm et al. 2008). A possible explanation for the discrepancy between these two studies was that although the adopted experimental pain-paradigm may reflect the SIS in terms of the painful structures, it might not reflect the adaptations in the central nervous system seen with chronic pain (Bandholm et al. 2008).

Considering the literature about this topic, the lack of studies on steadiness in subjects with SIS is evident. Although the study of Bandholm et al. (2006) has contributed a lot, the subjects evaluated in their study were engaged in upper-body training and, therefore, the behavior of steadiness may be different in subjects with SIS not engaged in upper extremity training. As such, new studies

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are necessary to assess steadiness in subjects with SIS, as well as which mechanisms might be responsible for possible deficits. The time to reach stability during a submaximal activity and the physical function status of the subjects would also be important tools to gain better knowledge of steadiness. It was hypothesized that both peak torque and steadiness would be impaired in these subjects. The purpose of this study was to assess peak torque and torque steadiness during isometric abduction in subjects with SIS and to compare the results of the SIS group to that of a control group of subjects with no upper limb disorders. This study also aimed to assess the physical function status of the subjects.

Methods

Subjects

Twenty-seven subjects (9 females and 18 males, 33.48 ± 9.94 years; 77.52 ± 14.78 kg; 174 ± 10 cm) with unilateral SIS participated in this study. The duration of their shoulder pain (self reported) was 31.31 ± 33.09 months. The subjects were first evaluated and characterized with SIS by a physical therapist and later, the diagnosis was confirmed by an orthopedic physician. The clinical diagnosis of SIS was made following the clinical criteria of reproduction of pain by at least three of the tests: Neer, Hawkins, Jobe, Speed, and Gerber. Ultrasonography was made to determine cuff tears by an experienced musculoskeletal ultrasonography radiologist. Ultrasonography has high accuracy (98.1%) for identifying rotator cuff tears (Ardic et al. 2006).

The involved side was the dominant side in 17 of the subjects. Subjects who were pregnant or had histories of shoulder injury, torn tendons, ligamentous laxity based on positive Sulcus test and Apprehension test, previous shoulder or neck surgery, systemic illnesses, corticosteroid injection 3 months prior to evaluation, and physical therapy 6 months prior to evaluation were excluded. A total of 31 subjects with SIS were evaluated, but four were excluded because they did not meet the remaining inclusion criteria (based on ultrasound imaging, one had a full thickness supraspinatus muscle tear, one had a full thickness subscapularis muscle tear, and one had subluxation of the long head biceps tendon; another one had diabetes based on self report).

The control group was matched to the SIS group with respect to age, weight, height, and level of physical activity (Table 1). It consisted of 23 healthy and active subjects (8 females and 15 males, 32.26 ± 9.04 years; 75.48 ± 12.98 kg, 173 ± 8 cm) with no upper limb disorders. Active subjects were considered those who had at least 30 min of physical activity daily (Booth and Lees 2006).

Table 1 Characteristics of the subjects

	Control group ($n = 23$)	SIS groups	
		Dominant involved side ($n = 17$)	Nondominant involved side ($n = 10$)
Age (years)	32.26 ± 9.04	34.35 ± 9.86	32.00 ± 10.41
Weight (kg)	75.48 ± 12.98	75.18 ± 10.33	81.50 ± 20.34
Height (cm)	173.0 ± 8.0	173.0 ± 8.0	175.0 ± 13.0

Results are mean \pm standard deviation

This project was approved by the Ethics Committee of the University. The subjects gave their written and informed consent agreement to participate in this study, which was conducted according to the Helsinki Statement.

Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire

The DASH questionnaire was applied before the peak torque and torque steadiness evaluations. This questionnaire was previously used to assess subjects with SIS (Camargo et al. 2007; Camargo et al. 2009). The DASH self-assessment questionnaire contains 30 questions to measure physical function and symptoms of the upper limbs. Each question has five possible responses, ranging from “no difficulty” to “unable to perform activity,” and is scored on a rating scale from 1 to 5. The questionnaire score is calculated by applying an established formula in which the maximum score is 100, which indicates the worst possible condition (Hudak et al. 1996).

Peak torque and torque steadiness evaluation

Peak torque and torque steadiness were measured during isometric abduction of the shoulder using an isokinetic dynamometer. The sampling frequency was set at 100 Hz. During the evaluation, the subjects were assessed in the seated position and stabilization of the trunk was provided by diagonal and pelvic straps. They were positioned with the arm in the scapular plane, neutral rotation, and 80° abduction with the elbow in full extension. The axis of rotation for abduction movement was aligned with the mechanical axis of the dynamometer. For this movement, the axis of rotation approximates the axis of the acromioclavicular joint, which connects the distal end of the clavicle to the anterior medial portion of the acromial process. Previous study has demonstrated the system to be setup as described (Camargo et al. 2008). Gravity effect torque was measured with the arm relaxed in 80° of abduction. This is the torque effect produced by the weight of the limb and the attachment. This is done by the dynamometer, recorded by the

software, and added to movements against gravity, and subtracted from movements assisted by gravity. It is used to eliminate the additional torque applied to the muscle tested and gives a measure of true muscle torque production.

Three abduction maximal voluntary isometric contractions (MVIC) of 5-s duration with an interval of 2 min between the trials were performed to determine the peak torque. The values of peak torque presented on the results have the gravity effect torque added because the movement was performed against gravity. However, to calculate the target torque (35% MVIC, as proposed by Bandholm et al. 2006), the gravity effect torque was subtracted from the peak torque and then it was added again to the target torque because the torque on the screen (feedback to the subjects) starts with the gravity effect torque (Fig. 1). For the assessment of the torque steadiness, three trials were performed at the target torque for 10 s each, with a rest period of 1 min between the trials. The subjects were allowed to see the monitor for visual feedback in order to reach and maintain the target torque.

Data analysis

The variable for shoulder abduction MVIC was the peak torque at 80° of abduction in the scapular plane, as described before, expressed as the highest torque among the three abduction MVICs.

All data from torque steadiness were reduced using MatLab® software (version 7.0.1, MathWorks Inc., Natick, USA). The isometric torque steadiness variables were expressed as the standard deviation (SD) and coefficient of

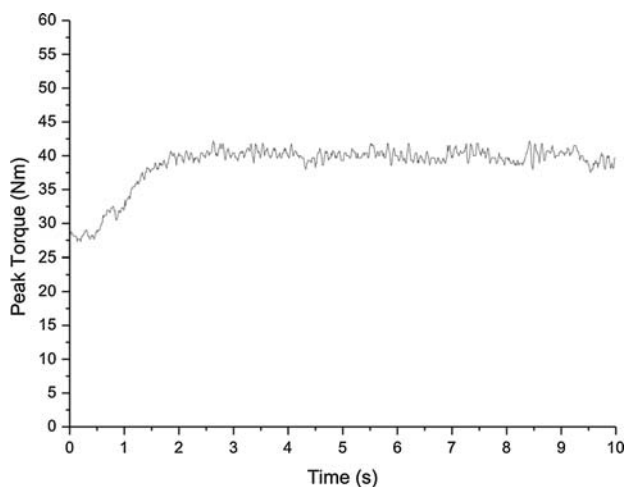


Fig. 1 One trial of shoulder-abduction force steadiness at 80°, in the scapular plane, of one subject. The subjects were supposed to maintain 35% of MVIC during abduction for 10 s. The torque does not start from zero because the torque on the screen starts with the gravity effect torque. Gravity effect torque was measured with the arm relaxed in 80° of abduction. This is the torque effect produced by the weight of the limb and the attachment

variation (SD/mean torque \times 100, CV) of the torque fluctuations within an 8-s window (the first two-seconds were discarded to avoid the initial phase and adjusting phase, as suggested by Lavender and Nosaka (2007)). The SD of torque is an absolute measure of the amplitude of the torque fluctuations that scales with the target torque exerted. Thus, CV of torque is used as a measure of the fluctuations expressed as a percentage of the mean torque exerted (normalized to the mean torque).

The high frequency component of the torque steadiness was analyzed by a Fast Fourier Transform (FFT). In order to allow the analysis of the high component, the signals were first high-pass filtered using a second-order zero-lag Butterworth filter at 5 Hz. The definition of the cut-off frequency was based on a previous spectral analysis of the whole signal. This previous analysis showed a clear division between low and high frequencies that compose the torque steadiness signal. In general, the low frequency component was concentrated between 0 and 4 Hz, while the high frequency component ranged from 8 to 15 Hz. The FFT was performed and the median frequency and relative power of the higher frequencies were calculated. In order to obtain the relative power, the total power was divided by the peak power.

Stability time was another torque steadiness variable evaluated (Fig. 2). The 10 s of contraction was considered for the evaluation of this variable. Stability time is described as the measure of time from the start of the muscular contraction to the point of a pattern of stability. In order to identify the point at which stability is reached, a windowing method was applied. Each window had a length of 0.4 s, and a 50% overlap between windows was used. The stability time was defined as the moment when the mean torque for window x was within the interval between the mean torque -1 SD and mean torque $+1$ SD computed for the reference window. In order to ensure that the stability pattern was reached, the windows $x + 1$ and $x + 2$ were also compared with the reference window, applying the same criteria. The reference window was a 2-s window established by the tester during the data processing, and it is described as a pattern of stability, i.e., when the torque fluctuations were minimal within the 10-s window.

Reliability of stability time

We determined both intertester and intratester reliability when processing stability time. Two testers performed the data processing twice, with an interval of 1 week between each processing. The intraclass correlation coefficient (ICC) was calculated using results of stability time for both intra and intertester comparisons. Results showed a high reliability, with ICCs at 0.98 and 0.95 for intratester (tester 1 and 2) and intertester (processing 1 and 2), respectively. Although

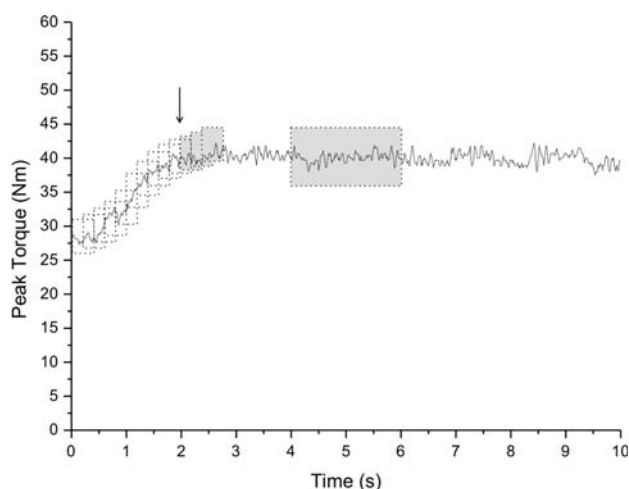


Fig. 2 Illustration of the windowing method applied to identify the stability time. The *largest gray box* represents the 2-s reference window, established by the tester to represent a period of stable torque within the recording. The windowing method is shown through the *dotted boxes*. Each window represents 0.4 s, and between them there is an overlap of 50%. In order to identify the stability time, three windows are compared so that all of them must have their mean value within the range of the mean value ± 1 SD calculated for the reference window. The method starts comparing window x , $x + 1$, and $x + 2$ and then, $x + 1$, $x + 2$, and $x + 3$, until it reaches the criteria. The *arrow* indicates the stability time for this trial and the *small gray boxes* represent the ones that have reached the established criteria

a mathematical algorithm was applied to the signals, inter-tester and intratester reliability were not 1.00 because the 2-s reference window was chosen visually by the testers. Since the choice of window is a subjective procedure, both inter-tester and intratester comparisons may differ.

Statistical analysis

Data are presented as mean and standard deviation. The mean values of the three trials of each evaluation were considered for statistical analysis. The results were analyzed using the software for statistical analysis NCSS (NCSS, Kaysville, UT). Normality tests were conducted for all dependent variables. Only the data from the DASH questionnaire were not normally distributed, so the nonparametric Mann–Whitney test was used. The data from peak torque and torque steadiness were normally distributed. For the following statistics, considering that dominance could affect the results, the SIS group was divided into two groups: (1) SIS with the dominant involved side and (2) SIS with the nondominant involved side. For each dependent variable (peak torque, SD, CV, stability time, median frequency, and relative power), a two-way repeated measures ANOVA was used to test for main effects of group (SIS with dominant involved side, SIS with the nondominant involved side and control group) and side (noninvolved versus involved for SIS subjects and dominant versus non-

Table 2 DASH score from the control group and SIS groups

	Control group ($n = 23$)	SIS groups	
		Dominant involved side ($n = 17$)	Nondominant involved side ($n = 10$)
DASH score (minimum–maximum)	0.98 ± 1.79 (0.00–5.83)	$22.64 \pm 17.53^*$ (1.66–50.83)	$18.00 \pm 12.47^*$ (6.66–44.16)

Results are mean \pm standard deviation

* $P < 0.05$, when compared to the control group

dominant for control subjects), or for interactions of group and side. A P -value of less than 0.05 was considered significant.

Results

Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire

DASH score was significantly higher ($P = 0.0001$) for both SIS groups when compared to the control group (Table 2).

Peak torque and torque steadiness

For all variables analyzed (peak torque, SD, CV, stability time, median frequency, and relative power), there were neither significant interactions between group and side ($P > 0.05$), nor were there significant main effects of group and side ($P > 0.05$). Table 3 shows the results for all variables.

Control and SIS groups showed an average of 60.45 ± 22.43 Nm for peak torque, 1.44 ± 0.52 Nm for SD, $4.20 \pm 1.20\%$ for CV, 2.54 ± 0.91 s for stability time, 11.59 ± 1.38 Hz for median frequency, and $30.83 \pm 11.32\%$ peak for relative power during isometric abduction of the shoulder.

Discussion

This study brings new approach on the evaluation of torque steadiness describing aspects of time and frequency domains. Peak torque and torque steadiness were not affected during isometric abduction of the shoulder in subjects with SIS. These findings are not supportive of the hypothesis that the SIS groups would present impaired steadiness when compared to a control group.

The calculation of the SD and CV for evaluation of the steadiness is frequently used in the literature (Bandholm et al. 2006, 2008; Lavender and Nosaka 2007; Shinohara

Table 3 Variables of isometric abduction in the control and SIS groups

	Control group (<i>n</i> = 23)		SIS dominant involved side (<i>n</i> = 17)		SIS nondominant involved side (<i>n</i> = 10)	
	Dominant side	Nondominant side	Dominant involved side	Nondominant uninvolved side	Dominant uninvolved side	Nondominant involved side
Peak torque (Nm)	61.67 ± 22.69	59.94 ± 23.59	63.13 ± 22.35	58.55 ± 22.76	58.87 ± 23.12	59.06 ± 23.26
Standard deviation (Nm)	1.40 ± 0.39	1.37 ± 0.40	1.48 ± 0.63	1.39 ± 0.51	1.57 ± 0.68	1.57 ± 0.73
Coefficient of variation (%)	4.00 ± 1.05	4.20 ± 1.20	3.99 ± 1.28	4.18 ± 0.81	4.64 ± 1.82	4.48 ± 1.52
Stability time (s)	2.53 ± 0.86	2.23 ± 0.65	2.77 ± 0.59	2.60 ± 1.04	2.69 ± 1.11	2.60 ± 1.44
Median frequency (Hz)	11.71 ± 1.19	11.84 ± 1.19	11.35 ± 1.35	11.12 ± 1.49	11.52 ± 1.57	11.92 ± 1.82
Relative power (% peak)	31.53 ± 11.43	30.65 ± 11.87	32.31 ± 11.33	29.97 ± 11.39	30.32 ± 11.86	30.22 ± 11.70

Results are mean ± standard deviation

et al. 2003; Tracy et al. 2007). The SD is more representative of steadiness than the CV because the SD is an absolute measure of variability, while the CV accounts for variability relative to the magnitude of the mean torque, a relative variability measure as proposed by James (2004). However, the description of the frequency domain can be a powerful tool in providing information about the response of muscles, joints, and their control (Baratta et al. 1998). This information may be useful to help understand the practical effects of tissue properties on the overall physiologic system's response (Baratta et al. 1998).

There is only one study that evaluated steadiness in subjects with SIS and this study used SD and CV for assessment of the steadiness (Bandholm et al. 2006). Bandholm et al. (2006) have not observed deficits in muscle strength and steadiness during isometric abduction in subjects with SIS. They explained this finding by the fact that all subjects participated in upper-body physical activities that require performing near-maximal muscle contractions. The authors believe that excitatory effects of upper-body physical activities could have balanced inhibitory effects of the shoulder pain on the abduction α -motoneuron pool. These findings are in agreement with this study in which no deficits were found in peak torque and steadiness during isometric abduction of the shoulder. In this study, the SIS groups were not engaged in upper-body training and they were matched to the control group with regards to the level of physical activity. However, according to the DASH score, it is possible to mention that the SIS groups presented a relatively high physical function status. This fact may have prevented an imbalance in the α -motoneuron pool and contributed to the similarity in strength and steadiness among the groups.

SIS and fluctuations in force/torque have also been linked to alterations in muscle activity (Graves et al. 2000; Shinohara et al. 2003; Phadke et al. 2009). Although muscle activity was not evaluated in this study, we speculate if our subjects presented altered muscle activity since Bandholm et al. (2006) have not identified differences in

muscle activity between SIS and control groups during isometric contractions.

No differences were found between dominant and non-dominant sides. Upper extremity dominance effect is still controversial in literature. It seems that dominance effect may be found particularly in unilaterally dominant upper-extremity-sport athletes (Ellenbecker and Davies 2000; Silva et al. 2006). Other studies are in accordance with the results of this study, where no side-to-side differences were found in subjects with a more symmetrical use of the arms (Camargo et al. 2008; Gołebiewska et al. 2008; Mattiello-Rosa et al. 2008). However, it has been suggested that bilateral differences in peak torque of less than 10% could be considered normal, while differences of 10–20% indicated a probable abnormality (Ellenbecker and Davies 2000; Sapega 1990). It was a surprise to find similarity also between involved and uninvolved sides. Some form of supercompensation is usually expected in the uninvolved side, and/or detraining in the involved side. However, as previously described, we believe that the relatively high physical function status performed with the upper limbs by the SIS groups and the more symmetrical use of the arms may have inhibited the supercompensation and/or detraining of the uninvolved and involved sides, respectively.

In order to test whether pain could reduce steadiness, Bandholm et al. (2008) induced experimental muscle pain in healthy subjects and they verified decreased steadiness during isometric abduction. The authors suggested that acute effects of experimental pain might not reflect the adaptations in the central nervous system seen with chronic pain (Bandholm et al. 2008). Although the validity of experimental pain models for chronic pain conditions is questionable, we suggest that in this study the chronicity of the condition of the subjects can be one possible explanation for not finding the expected impairment in the SIS groups. Initial onset of symptoms was reported to be an average of 2.6 years. Possibly, alterations in steadiness would be noted in subjects with more acute pain.

The visual feedback provided in this study is an important issue to be discussed because it was demonstrated to attenuate the fluctuations (Christou 2005; Slifkin et al. 2000). Visual information can be utilized by the motor system to meet the goals of matching the target torque, and minimizing the fluctuations around (Slifkin et al. 2000). Given this fact, our results should be interpreted with caution. This issue can be a limitation in identifying differences in steadiness among the groups.

Afferent detection of fluctuations in force was suggested to have an important role in the controlling of force (Bandholm et al. 2008). As such, it is also important to consider that stage II SIS has been associated with proprioceptive deficits (Machner et al. 2003) and apoptosis in the supraspinatus tendon (Tuoheti et al. 2005) in subjects who were treated with subacromial decompression. These aspects might alter the impulse activities of the afferents from the muscle spindles and, more likely, Golgi tendon organs leading to a modification of the ability of the central nervous system to utilize this afferent information to control force output during isometric contractions and impair the sensory-motor control in subjects with SIS. As none of the subjects in this study had indication for subacromial decompression, this may have contributed for not finding alteration in steadiness. We speculate that a possible impairment in afferent information may be associated to later stages of the SIS. Nevertheless, to conclude on the possible disturbance of afferent feedback, a different experimental setup is needed in which high frequency perturbations are applied (Schouten et al. 2008).

Conclusion

The results of this study showed that steadiness is preserved by SIS during isometric abduction of the shoulder. However, further research is required in subjects with more acute pain or in late stage of the syndrome in order to optimize rehabilitation regimes for SIS. An analysis without visual feedback would also be interesting to evaluate the effect of SIS on steadiness.

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