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Short range of motion isokinetic testing of wrist flexors and extensors strength in normal subjects and patients with carpal tunnel syndrome

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Abstract

The purpose of this study was to compare the utility of measuring wrist flexors and extensors strength derived from 'full' range of motion (FRoM): 60° of flexion to 30° of extension, and 3 equally spaced short ranges of motion: SRoM1, 60-30° and SroM2, 30-0° of flexion and SRoM3, 0-30° of wrist extension. Fifteen apparently healthy subjects and 8 patients suffering from unilateral carpal tunnel syndrome (CTS) participated in the study. In all participants SRoM1 findings closely resembled those obtained from FRoM. In the patient groups, the muscular strength of the uninvolved side was not different from that of the healthy subjects. On the other hand, based on a bilateral comparison (involved vs. uninvolved hand) the mean total weakness (in concentric and eccentric modes) was significantly higher in flexion (56.4±17.3%) than in extension (39.8 ±15.5%) but highly symmetrical between FRoM and SRoM1. While supporting the interchangeable use of FRoM and SRoM isokinetic testing this study highlights an hitherto unreported dynamic weakness of the wrist extension-flexion apparatus which may partly account for the general reduction in hand function reported by patients with CTS.

Keywords: **isokinetic, wrist, carpal tunnel syndrome**

Introduction

The two major clinical application of isokinetic dynamometry are the quantitative determination of muscular performance status and monitoring its variation following trauma or intervention (1, 5). Strength is most commonly defined in terms of the peak moment (torque) which derives from the muscle moment-position curve that is obtained from testing along a substantial sector of the relevant joint's range of motion (RoM). The application of this 'full' RoM (FRoM) testing is by no means unique. Recent studies comprising trunk (6), knee (3,4,13) and shoulder (7) muscles have indicated that the use of a much shorter range of joint motion (SRoM) could yield similar findings while preserving subject/patient safety and comfort. Specifically in studies relating to knee flexion and extension strength an FRoM of 90° was split into 3 short sub-ranges of motion: 0-30°, 30-60° and 60-90° of flexion. The SRoM-based strength scores, particularly those derived from the 30-60° (middle) sector were strongly correlated ($r>0.9$) with their FRoM counterparts while evidencing clinically acceptable reproducibility under both concentric and eccentric conditions (4,13). Hence under the prescribed conditions SRoM may effectively replace FRoM as the testing technique in normal subjects.

However, the clinical utilization of SRoM testing for assessing weakness has so far been reported only in terms of comparison to normal reference values. In one such study trunk extension strength in patients with chronic low back dysfunction was compared with that of healthy subjects (8). This patient group exhibited typical concentric and eccentric weakness pattern comparable to findings reported previously (15) but no within-patient SRoM vs. FRoM analysis was performed.

Whether the SRoM approach is equally applicable in unilateral muscle weakness has not hitherto been examined. A recent preliminary study has indicated that the only valid indicator of unilateral muscular weakness was based on comparing the strength of the involved side muscles with their homologous counterparts in the uninvolved side (17). Moreover, it has been suggested that a 20% difference in strength between the involved and apparently sound side could serve as a benchmark for indicating a pathology or disturbed muscle function (14).

A typical musculoskeletal pathology in which weakness, sometime of a unilateral nature, is a major symptom and thus can serve as a model for assessing the clinical utility of SRoM testing is carpal tunnel syndrome. Patients afflicted with this syndrome often complain of weakness that is expressed as a difficulty in gripping and making fist, as well as dropping of objects. In chronic cases wasting of the thenar muscles may also occur. Although isometric tests relating to hand grip, pinch and thenar muscles strength have been extensively reported (10) no corresponding isokinetic studies could be traced. However, based on previous research (9,11) we assumed that isokinetic testing, FRoM- or SRoM-based, of wrist muscles in patients with unilateral CTS could be performed. Moreover, based on the symptoms we hypothesized that the patient group would present with weakness of wrist muscles and that this weakness as expressed by the strength of the involved vs. uninvolved side muscles would be similar irrespective of the applied range of motion: short or ‘full’.

Methods

Experimental approach to the problem

Using an isokinetic dynamometer equipped with a special attachment for measuring wrist muscles strength, the aim of this study was twofold: to test the feasibility of short RoM isokinetic testing in apparently healthy subjects and patients suffering from unilateral CTS and to compare the extent of the weakness as derived from the two RoMs: the 'full' and the short.

Subjects

A group of 15 apparently healthy women, aged 27-38 with height and weight of 155-172cm and 57-65kgf, respectively, took part in the study. Seven women were right dominant. All subjects were pain free during the tests and took no analgesics for at least 6 months prior to the tests. This group was designated as the control group Another group of 8 women, physician-diagnosed with unilateral CTS (clinical examination and EMG study) affecting the dominant hand, without any other musculoskeletal pathology of the upper extremity, formed the experimental group. Their age, height and weight were 29-40, 158-168cm and 54-62kgf, respectively. All symptoms (pain and tingling) appeared at least 6 months prior to the study but were not present at least two weeks prior to the tests. As a result, no medications were taken by the patients during the time of testing. All patients were offered surgery for relief of symptoms but declined. This group was designated as the patient group. Tests were performed in the Biomechanics Lab, the Zinman College of Physical Education. All subjects signed a consent form. This study was approved by the local Institutional Review Board.

Instrumentation and Procedure. Data was collected using a Biodex System 3 isokinetic dynamometer (Biodex Inc. Shirley, NY). The test was conducted with the subject in the standing position, forearm supported in horizontal position and the hand gripping a handle. The lever arm thus swiveled in the horizontal plane and its axis was substantially aligned with the ulnar styloid process to allow free wrist flexion-extension movement. The 'neutral' position of the hand was defined as that in which the metacarpal bones extended straight forward from the forearm. From this position the hand was brought passively to position which corresponded to approximately 30° of extension namely forming an angle of about 150° between the forearm and metacarpal bones. From this initial position the hand was passively brought into 60° of flexion covering altogether an arch of 90° (the FRoM). Following RoM adjustment a warm-up consisting of 5 submaximal concentric flexion-extension performed at 90°/s was conducted, which was followed by actual testing.

In the patient group, the test was performed bilaterally with the uninvolved side tested first. In the control group tests were limited to the dominant side. Visual Analogue Scale (VAS) pain scores of the patients were recorded prior to the test. Although some patients complained of pain particularly during the eccentric exertions and at extreme hyperextension, none of the patients asked for the test to be terminated.

For both groups within RoM ('F' or 'S') testing consisted of two parts: reciprocal concentric flexion and extension followed, after a 2 min break, by reciprocal eccentric flexion and extension. In flexion the hand moved from the initial (30° of extension) towards 60° of flexion while for extension the direction was reversed. The FRoM tests were conducted at 90°/s resulting in a so-called nominal movement time (NMT) of 1s (13). Subjects were encouraged verbally to exert maximal effort. Five repetitions were performed and the average peak torque (PT) value of the 3 best repetitions was considered the outcome score. After a 2min pause the eccentric test was conducted using the same order but with reversed directions namely 90 to 0° for flexion and 0 to 90° for extension.

For SRoM testing, the 90° angular sector of the FRoM was decomposed into 3 SRoMs as follows:
SRoM1: from 60° to 30° of wrist flexion
SRoM2: from 30° to 0° of wrist flexion
SRoM3: from 0° of wrist flexion to 30° of extension

The order of testing was random i.e. some subjects started with 0-30, 30-60 and 60-90° and others vice versa: 90-60, 60-30 and 30-0°. There was an inter-SRoM pause of 1min. The same order of 5 reciprocal concentric tests followed 2 min later by 5 reciprocal eccentric tests was maintained. The SRoM tests were conducted at 30°/s resulting equally in an NMT of 1s.

Statistical analysis: Prior to data analysis the PT values and ratios were examined for normality using the Kolmogorov-Smirnov Z test. All values were relatively normally distributed (K-S values 0.42-0.1, p-value 0.22-0.99). For assessing the utility of the SRoM in normal subjects a repeated measure analysis-of-variance was used. Pairwise multiple comparisons were conducted in order to determine which means differed significantly, using Bonferroni procedure. In addition, to assess the relationships between the PT values within muscle groups and between ranges the Pearson correlation coefficient (r_p) was used. For determination of the extent of weakness (if any) in CTS patients, paired t-tests for the following conditions were performed: involved (I) vs. uninvolved (U) hand, in each range (FRoM, SRoM) and in each condition (concentric and eccentric, extension and flexion). All analyses were performed using the SPSS 14.0 program for Windows. Results were considered statistically significant when the P value was less than 0.05.

Results

Normal subjects

Wrist extension and flexion PT values in both contraction modes are outlined in Table 1. As evident, SRoM1-derived PTs resembled most closely their FRoM counterparts, based on both an absence of any significant difference between the two and an overall mean difference ([Concentric FLX + Eccentric FLX + Concentric EXT+ Eccentric EXT]/4) of less than 2%. SRoM2 exhibited a low mean difference of 2.7% relative to FRoM but together with SRoM3 yielded significant differences relative to FRoM in 2/3 of the combinations.

The eccentric/concentric (E/C) strength ratios were greater than 1 in all conditions (Table 2). No significant differences were indicated between FRoM and SRoM1 in either flexion or extension. However the ratio for SRoM3 was significantly smaller than either of the other 3 RoMs whereas FRoM and SRoM1 were significantly different from SRoM2. Table 3 reveals significant correlation coefficients between FRoM and the SRoMs: 0.76-0.91 and 0.78-0.95 in extension and flexion, respectively. These were higher than the within SRoM (e.g. SRoM1-SRoM2) coefficients.

Patients

In 7 patients, the level of pain as reflected by VAS scores (0-no pain at all, 100mm – maximal sensation of pain) ranged 39-61mm indicating a generally moderate level of pain. One patient rated her pain as 6.9 and complained of some discomfort after eccentric flexion. However all patients complied well with the test and none reported any negative effect or feeling after completion of the test.

Comparison of the strength of the apparently sound (U) hand and the corresponding values in normal subjects has yielded no significant differences. From Fig. 1 which depicts the PT values of the uninvolved (U) and involved (I) sides in the patient group a uniform and significant weakness within movement and contraction modes is apparent. In view of this finding, the strength ratio: (I/U)*100 was subtracted from 100 and averaged over the 4 individual weakness scores in each movement/contraction mode cell to yield the combined weakness score (CWS) outlined in Table 4. The mean CWS in flexion (concentric and eccentric) was significantly higher ($P<0.02$) in flexion (56.4±17.3%) than in extension (39.8 ±15.5%). Alternatively the mean total weakness (flexion and extension combined) was 50.0±20.2% and 46.2±12.1% in the concentric and eccentric modes, respectively. However, the difference between the modes was not significant. Moreover, across all possible combinations, absence of significant within-hand differences was noted only for the pair FRoM-SRoM1. Table 5 outlines the E/C ratios in both the involved and uninvolved hands. All ratios were greater than 1 except in a single case. Notably, none of the combinations indicated a significant difference between FRoM and SRoM1.

Table 7 indicates significant and clinically acceptable correlation coefficients between FRoM and the SRoMs in both the involved and uninvolved hand. For both hands the coefficients for extension were > 0.9 (except a single case of 0.89). For flexion the coefficients were generally slightly smaller but still > 0.9 in more than 50% of the cases.

Discussion

This main finding of this study is that wrist flexors and extensors strength may effectively be measured in normal subjects and patients with CTS using the short RoM approach, particularly when the angular sector designated as SRoM1 is applied. However various aspects which emerge from the results deserve further elaboration.

Muscular strength is not an absolute entity. First, it depends critically on the contraction mode: static or dynamic. Second, when its dynamic (isokinetic) variant is concerned a large number of variables such as the type of contraction, range of motion, test velocity, test position etc have an effect on the outcome. Indeed, as far as the range of motion is concerned no standard procedure exists and the diversity in this respect is quite large, particularly regarding joint systems like the trunk, shoulder and ankle. In some respect SRoM testing may be viewed as an hybrid between static and dynamic testing where one of the main objectives is to standardize the measurement protocol. Therefore irrespective of whether any of the SRoM-based scores are in agreement with those derived from FRoM, the previous may be applied and duly interpreted providing the results generally agree with those obtained in former well-conducted studies while conforming with physiological expectations.

As for the first, two studies have reported a range of 11-16N·m, based on tests conducted at 30-180°/s, for concentric wrist flexion in women (9,11). The present strength scores derived from both FRoM and SRoM were largely within this range. For concentric extension in women the PTs reported by the above studies ranged roughly 6-8N·m whereas in the present study the corresponding values were about 9N·m and 10N·m in FRoM and SRoM1, respectively (Table 1). Eccentric PT scores were reported only in one study and related to women's performance at 60°/s. Mean values were about 19N·m and 15N·m for wrist flexors and extensors, respectively (11). In the present study the mean PTs for eccentric flexion and extension were between 11N·m and 13N·m.

Regarding the second element since the tests were conducted using a single velocity for each test RoM, examination of one typical physiological parameter: torque-velocity relationship is irrelevant. On the other hand as all tests included an eccentric component, the E/C ratios provide an important insight. The obtained scores (Table 2), in both groups, revealed excellent agreement with known values in normal subjects namely between 1-1.5 for the specific velocities that were used (5).

Thus based on the absolute (Table 1) and relative (Table 2) strength parameters, the findings relating to the normal group support the validity of the test procedure. Furthermore, the conspicuous similarity in findings between FRoM and SRoM1 as well as the high correlations between these testing variants (Table 3) strongly suggest that with respect to the strength profile SRoM1 and FRoM are interchangeable options for testing of wrist flexion and extension in both contraction modes in normal subjects.

The reason for the observed close association between SRoM1-based strength scores and their FRoM counterparts is not a straightforward one. It may be related to a combination of factors encompassing the location of SRoM1 within the total wrist excursion, the inter-muscular play in performing the various tests and the test position. As for the location of SRoM1, various values have been mentioned for normal wrist RoM: 120°, from 60° flexion to 60° extension (1); 150°, from 80° flexion to 70° extension (16) or 160°, from 85° flexion to 75° extension (12). Hence, SRoM1 does not probably correspond to the most shortened position of the wrist flexors and thus there is no risk of an active insufficiency of this group. On the other hand, it offers a favorable position for testing the extensors.

However what is not obvious is the possible role of grip muscles and its effect regarding the best compatibility with the FRoM among the 3 SRoMs. When performing an isokinetic test of flexion and extension of the wrist the fingers grip an handle which constitutes an integral part of the special wrist attachment provided by the manufacturer. Thus, instead of effecting a pure flexion-extension pattern by placing the lever arm-hand interface at the level of e.g. the metacarpal bones (the palm), this attachment mandates a firm grip of the handle, ostensibly in order to better stabilize the bio-mechanical axes alignment. This inevitably leads to load sharing by muscles not directly responsible for the measurement namely the wrist flexors may be assisted by the flexor digitorum profundus (FDP) and superficialis (FDS) while the wrist extensors may equally be supported by the extensor digitorum communis (EDC). Moreover, due to the eccentric function of the EDC during grip which is meant to block the active insufficiency of FDP and FDS, the eccentric strength of EDC is of particular significance during SRoM1, a fact that is borne out conspicuously by the negligible eccentric strength difference relative to FRoM in this angular sector. Therefore although from the length-tension relationship viewpoint wrist flexors would have been put in a better position to act at SRoM3, the above combination of factors point out to SRoM1 as being the preferred short RoM option.

Regarding wrist muscles function in patients with CTS, the similarity between the normal subjects-based findings with those derived from the uninvolved hand is significant. It underlines the fact that although in most cases the uninvolved hand was also the non-dominant one, irrespective of whether it was weaker prior to the symptoms, its level of functioning was similar to the dominant hand of normal subjects. This may indicate some adaptive effect. When the strength scores were considered (Table 4) a significant reduction was unveiled in both directions and contraction modes. Of particular importance is the fact that the muscles of the affected side exhibited a fairly uniform decrease in strength vis-à-vis all SRoMs, as clearly evident from Table 4. In other words, the force output decreased similarly without specifically affecting either of the sub-sectors. This is in agreement with the mechanical etiology of CTS namely a neuropathy resulting from a general compression of the flexor tendon apparatus without implicating a specific component of the muscles.

However, the observed weakness was significantly higher in the flexor apparatus, a finding that is in line with the clinical manifestation of CTS. Interestingly the combined weakness score (CWS) was highest in eccentric flexion; pain may be provoked more often with eccentric activities which are normally associated with higher muscular force output. In addition, eccentric contraction of the flexors is largely an unfamiliar activity of this muscle group and may be simulated by holding a balloon which undergoes inflation. This should be compared with the eccentric action of the extensors which takes place whenever grip is effected in order to preserve the appropriate length-tension relationship of the flexors. Thus although the eccentric extension is not a function that is consciously performed it is not foreign to the neuromotor apparatus, which may account for the relatively least marked weakness among the 4 that were tested.

To further probe the FRoM-SRoM duality, the E/C ratios in both hands were computed (Table 5). Interestingly, all mean values, save the case of SRoM3 of the uninvolved hand in extension yielded values that were greater than unity. Unusually high scores were found for the involved hand in both FRoM the and SRoM1, 1.72 and 1.92, respectively. This might reflect specific controlled force output during concentric contractions due to pain. At SRoM1, the hand is in its most flexed, a position that is more likely to be associated with provocation of pain in view of the decreasing size of the canal during wrist flexion (2). As expected from the foregoing analysis, FRoM was also consistently correlated with each of the short RoMs (Table 6) irrespective of the hand. Noteworthy the highest correlations were obtained with respect to concentric and eccentric extension but they were all within what is clinically acceptable, besides being highly significant.

The principal limitation of the study is the use of a wrist testing attachment that involved hand grip as a component during performance of wrist flexion and extension. Since the moment output consists of all participating muscles, the net share of the wrist flexors and extensors could not be determined based on this particular experimental design. However, in view of the synergistic patterns between the respective hand + wrist flexors and hand + wrist extensors, it stands to reason that the final conclusion is valid irrespective. One solution in future studies would be to better isolate the individual effect of purely wrist muscles by having the volar and dorsal aspects of the palm push and resist against an accommodating force pad. Another limitation relates to the choice of velocities: 30°/s and 90°/s, for SRoM and FRoM, respectively. The reason for this choice was the assumption that nominally the effective contraction times will be comparable. However the current findings do not allow the determination of optimal velocities. Further research is indicated with respect to this question. Finally a significant limitation was the small number of patients. In most patients, CTS occurs bilaterally and therefore isolating unilateral cases proved to be difficult. Care was taken to exclude those cases that were borderline resulting eventually in 8 patients only. On the other hand, the findings were, in our opinion, sufficiently clear to warrant reporting.

From the applied clinical point of view this paper vindicates the use of isokinetic testing for assessing the severity of wrist musculature involvement in patients with CTS. Normally, the functional status of hand muscles is evaluated using the standard instruments for grip and pinch strength. The findings derived from such tests may not reflect the full impact of CTS as clearly shown in this preliminary analysis.

Supplementing the latter with wrist muscles strength may provide clinicians with a broader and more meaningful picture and assist in designing a more efficient treatment plan.

To conclude, the findings of this study lend further support to the interchangeable use of full and short RoM isokinetic testing. Significantly they indicate that this methodology is applicable also in the case of wrist flexors and extensors where the sector between 30° and 60° of wrist flexion (SRoM1) is the recommended SRoM. Furthermore, this testing mode is as effective in patients with CTS as it is in normal subjects and therefore paves the way for its possible incorporation in the clinical setting.

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Table 1. Peak torque values (in N·m) for wrist flexion and extension: normal subjects.

RoM	FLXcon	FLXecc	EXTcon	EXTecc
FRoM Range	10.23±3.24* 6.4-15.9	11.97±2.59 7.7-16	9.11± 2.57 6.1 – 15.1	13.63±3.76 7.5-21.0
SRoM1 Range % diff	11.03±3.66 5.0-20.2 ------------------- +7.8	11.21±3.09 6.1-17.2 ------------------ -7.2	9.94±3.62 6.5-19.5 ------------------ +9.1	13.25±4.07 5.8-20.7 ------------------- -2.7
SRoM2 Range % diff	9.93±2.40 5.4-14.0 ------------------- -9.7	10.86±3.36 7.2-18.2 ------------------ +6.1	9.96±2.98 6.5-15.7 ------------------ +9.1	11.60±3.74 6.4-18.4 ------------------- -16.3
SRoM3 Range %diff	9.12±3.07 4.3-15.2 ------------------- -10.8	10.00±2.84 5.0-15.3 ------------------ -15.6	9.76±2.45 6.4-13.8 ------------------ +7.1	10.07±3.91 5.3-18.4 ------------------- -26.2
Sig.	SRoM1-SRoM3 P=0.004	FRoM-SRoM3 P<0.05	FRoM-SRoM2 P=0.004	FRoM-SRoM3, P<0.001 FRoM-SRoM2 P=0.003 SRoM1-SRoM3 P<0.001

EXT- extension, FLX – flexion; SRoM1: 0-30°, SRoM2: 30-60°, SRoM3: 60-90°;

*mean±SD; diff - % difference relative to FRoM, Sig. – significant differences between FRoM and any of the SRs, as well as between the SRs, at the specified contraction mode.

Table 2. Eccentric/concentric strength ratios: normal subjects.

RoM / Ratio	FRoM	SRoM1	SRoM2	SRoM3	Significance of differences
Flx_{ecc}/Flx_{con}	1.22±0.22	1.07±0.29	1.10±0.28	1.14±0.36	NS
Ext_{ecc}/Ext_{con}	1.53±0.40	1.42±0.57	1.19±0.32	1.04±0.36	<0.001*

* FRoM , SRoM1, SRoM2≠ SRoM3 and FRoM , SRoM1 ≠ SRoM2

Table 3. Correlation matrix between FRoM and SRoMs: normal subjects.

RoM	FRoM	SRoM1	SRoM2	SRoM3
FRoM	1.00	.87(Ex)**/.81(Fl)** C-C	.95**/.83** C-C	.89**/.78** C-C
SRoM1	.91**/.76** E-E	1.00	.85**/.53* C-C	.74**/.80** C-C
SRoM2	.85**/.78** E-E	.84**/.83** E-E	1.00	.93**/.62* C-C
SRoM3	.84**/.82** E-E	.80**/.55* E-E	.91**/.60* E-E	1.00

Ex - extension, Fl - flexion

SRoM1: 0-30°, SRoM2: 30-60°, SRoM3- 60-90°

C-C concentric vs. concentric, E-E eccentric vs. eccentric

** $P<0.01$, * $P<0.05$

Table 4. Bilateral strength differences and combined weakness score in patients with CTS according to group and test

		Flexion		Extension	
	RoM	I/U (%)	CWS(%)	I/U (%)	CWS(%)
Con	FRoM	48.27±25.03*	53.2±24.5	53.13±21.22*	46.8±18.7
	SRoM1	49.60±32.29*		51.63±20.94*	
	SRoM2	48.87±30.34*		53.35±19.38*	
	SRoM3	40.84±26.30*		54.69±19.91*	
Ecc	FRoM	42.81±19.89†	59.7±16.3	70.23±26.23†	32.8 ±16.9
	SRoM1	40.78±16.53†		63.49±19.44†	
	SRoM2	41.35±17.97†		67.65±19.42†	
	SRoM3	36.55±18.99†		67.62±16.08†	

Con – concentric, Ecc – eccentric; I – involved hand, U – uninvolved hand; CWS – combined weakness score; P – level of significance between U and I hands

* - P< .01, † - P<.001

Table 5. Eccentric to concentric strength ratios: Patients with CTS.

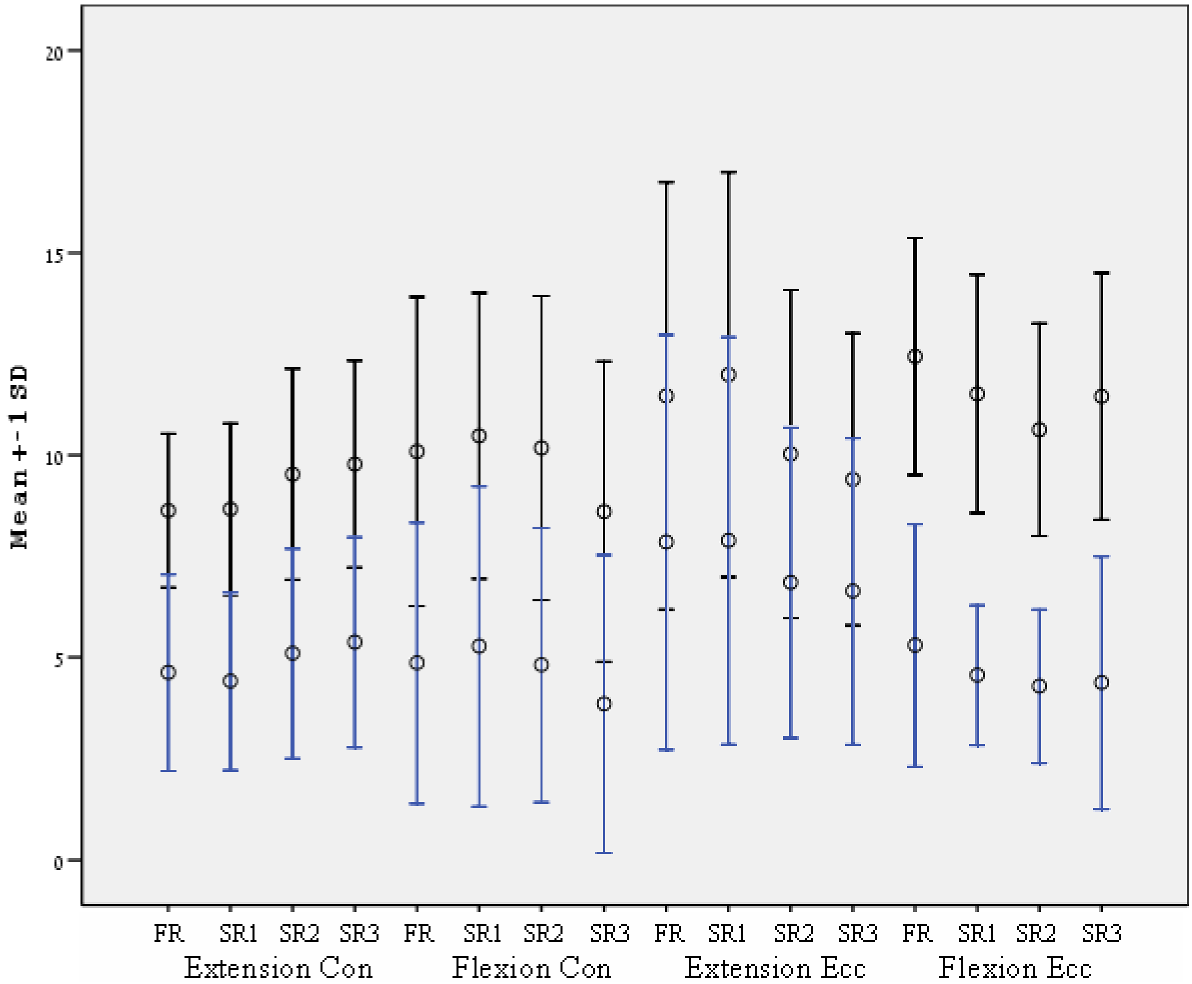
Side	RoM MOV	FRoM	SRoM1	SRoM2	SRoM3	Significance of differences
I	FLEX	1.34±0.46	1.20±0.60	1.15±0.52	1.54±0.77	NS
	EXT	1.72±0.83	1.92±1.25	1.35±0.39	1.26±0.45	$P<0.05$, FRoM≠ SRoM3
U	FLEX	1.31±0.28	1.16±0.31	1.11±0.29	1.45±0.44	$P<0.01$ FRoM, SRoM3 ≠ SRoM2
	EXT	1.35±0.62	1.45±0.77	1.07±0.40	0.98±0.39	$P<0.002$ FRoM, SRoM1 ≠ SRoM2, SRoM3

Table 6. Correlation matrix between FRoM and SRoMs: Patients with CTS.

Movement	Mode	Side	SRoM1	SRoM2	SRoM3
Flexion	Con	I	0.87	0.95	0.84
		U	0.89	0.98	0.81*
Flexion	Ecc	I	0.92	0.94	0.94
		U	0.74*	0.91	0.98
Extension	Con	I	0.95	0.98	0.94
		U	0.90	0.94	0.89
Extension	Ecc	I	0.98	0.96	0.95
		U	0.98	0.92	0.91

all r’s < 0.01 except *<0.05; Con – concentric, Ecc – eccentric; I – involved hand, UI – uninvolved hand.

Fig. 1. Peak torque values of wrist flexors and extensors of the uninvolved (black lines) and involved (blue lines) hands in the different test RoMs and contraction modes.



FR – full RoM

SR1 – 60-30º wrist flexion

SR2 – 30-0º wrist flexion

SR3 – 0-30º wrist extension