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Differences in Active Range of Motion Measurements in the Upper Extremity of Patients with Writer's cramp (WC) Compared with Healthy Controls

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Abstract

Study Design—Exploratory Case Control Study

Introduction—WC is a type of focal hand dystonia. The central nervous system plays a role in its pathophysiology, but abnormalities in the affected musculoskeletal components may also be relevant.

Purpose of the Study—We compared the active range of motion (ROM) in patients with WC and healthy volunteers (HVs) and correlated the findings with disease duration and severity.

Methods—Affected limb joints were measured with goniometers. Patients were assessed at least 3 months after their last botulinum toxin (BoNT) injection and strength was clinically normal. T-tests were used to compare the ROMs of WC with matched HVs. The Spearman correlation coefficient assessed the relationship of active ROMs to the disease duration and handwriting sub-score of the dystonia disability scale (DDS).

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Results—ROMs of D1 metacarpophalangeal (MCP) joint extension, D2 and D5 MCP flexion were significantly smaller in WC and distal interphalangeal joint extension in D3 and D5 were significantly greater compared with HVs. There were negative correlations between D2 MCP flexion and disease duration and with DDS.

Discussion—Abnormalities in ROMs in WC were found. Severity and disease duration correlated with reduced D2 MCP flexion. This may be related to intrinsic biomechanical abnormalities, co-contraction of muscles, or a combination of subclinical weakness and atrophy from repeated BoNT injections.

Conclusions—Hand Biomechanical properties should not be ignored in the pathophysiology of WC.

Level of Evidence—2c

Keywords

Focal hand dystonia; Writer's cramp; Biomechanical assessment; Botulinum toxin; Dystonia Disability Scale

1. Introduction

The task-specific focal hand dystonia (FHD) writer's cramp (WC) is characterized by inappropriate activation of muscles leading to impairment of hand control while trying to write (Video 1). FHD typically occurs in individuals who perform repetitive task-specific activities like writing, typing or playing a musical instrument [1]. While other aspects of hand function appear normal, stereotypical tasks lead to abnormal co-contraction of muscles resulting in unusual postures during writing in those with WC [1,2].

The pathophysiology of WC is only partially known and studies suggest that the central and peripheral nervous systems play an important role in the etiology of this disorder. Loss of inhibitory mechanisms at cortical [3,4,5], brainstem [6] and spinal levels [7], abnormal sensory function [8,9,10], and abnormal cortical plasticity [11,12] in genetically predisposed individuals likely lead to this life altering condition. Environmental [13] and biomechanical factors [14,15] also seem to contribute to the pathophysiology of this condition. Leijnse and colleagues proposed a theoretical model of how biomechanical abnormalities could trigger FHD in musicians, and this model might be also applicable for other FHDs. The authors conclude that enhanced muscle forces, finger trajectory limitations, joint motion limitations, and neuro-musculoskeletal defects may cause problems with playing musical instruments [16]. In the past two decades, there has been some interest on the biomechanical function of the hands in patients with FHD. A comparison of the biomechanics of the hands of musicians with FHD to unaffected musicians with respect to passive and active range of motion (ROM) of the hand joints showed some differences. Two-thirds of the FHD group had marked limitation of passive and active abduction between digits 2 to 5 of both hands [17]. Also, Byl and colleagues showed limitations in finger spread, forearm supination, and shoulder external rotation in patients with musician's cramp (MC) compared to unaffected individuals [18]. Wagner showed differences in the hand biomechanics of pianists with FHD

compared to healthy pianists in hand size and shape, joint resistance and muscle forces at the joints [19].

To date, active ROM measurement has not been well studied in patients with WC, and its relation to disease severity and duration are not clear. A study comparing physical characteristics of patients with MC to WC [20] showed that the average of ROM (reported as a percentage of total possible motion) of the upper extremity in patients with MC was greater than in WC (81% vs. 67%). This study did not report ROM of all joints in the upper extremity separately. It was insufficient to make a conclusion as to which joints contributed more to the limitation of ROM in both WC and MC. Therefore, our study explored the differences in the active ROM of all joints separately in the upper extremity of patients with WC compared to healthy subjects. The severity of WC can be objectively assessed using the Writer's Cramp Rating Scale (WCRS) [21] and the Arm Dystonia Disability Scale (DDS) [22]. We correlated the active ROM of patients with WC with the DDS-handwriting sub-score, and disease duration.

2. Purpose of the Study

To better understand the pathophysiology of WC, we explored the possible biomechanical differences in those with WC compared with matched healthy volunteers (HVs) focusing on active ROM. In patients with WC, we also investigated the correlation between active ROM and disease severity using DDS-handwriting sub-score, and disease duration.

2. Methods

2.1 Subject Selection

Subjects were recruited from the Human Motor Control Section clinic. Eight patients participated in the study prior to administration of their regularly scheduled BoNT injections and after its effects had completely worn off by subjective impression and routine clinical assessment. All subjects were receiving onabotulinumtoxin-A. All subjects were interviewed and examined prior to participation. The mean age and standard deviation (SD) of the patients was 59.3 ± 11.3 years old (range: 48–70 years). Eight HVs were age- and handedness-matched and served as the control group. The mean age and SD for the HVs was 57.8 ± 10.8 years (range: 47–68 years) (Table 1).

This study was approved by the Institutional Review Board of the NIH/NINDS. All participants signed a consent form prior to participation. HVs also underwent physical and neurological examinations prior to their participation. A board certified neurologist with special training in movement disorders assessed the disease severity of patients with WC using the DDS [23].

2.2 Measurements of joints

All upper extremity joints involved during the writing tasks were successfully measured (Table 3). Using 4 differently sized goniometers, we measured the active ROM of these joints during flexion and extension, during pronation and supination of the forearm, and during radial and ulnar deviation of the wrist. Subjects were asked to perform the above-

mentioned actions on their own. Abduction and adduction of each digit were not measured since these movements were not identified as being part of the normal biomechanical process of handwriting. The active ROM of all joints including fingers, wrist, forearm, and elbow joints were measured according to a standard protocol which was described previously [24].

2.3 Muscle Study

The diagnosis of WC and disease progression information were obtained from reviewing patients' charts and reviewing patients' history. The affected muscle patterns at the initial visit and 12 months prior to participating in our study are reported in Table 2.

2.4 Data Analysis

The test of normality assumption was performed with the Shapiro-Wilk test based on the residuals. Two-sample t-test was used to evaluate the difference in each outcome measure between patient and HV groups. Spearman correlation coefficient analysis was used to assess the linear relationship of active ROMs with disease duration, and DDS-handwriting sub-score. All of the above-mentioned statistical analyses were performed using SAS version 9.2, with $p = 0.05$ considered a significant level. Since there are many measures, the results are considered exploratory and correction for multiple comparisons was not done.

3. Results

The mean age of onset of patients with WC was 47.9 ± 6.3 years (range, 36–56 years). Patterns of WC were flexor type in 7 patients and extensor type in 1 patient. The mean duration of symptoms was 19.1 ± 5.9 years (range, 12–30 years); the mean number of BoNT clinic visits was 25.8 ± 14.9 visits (range, 5–45 visits). The average duration of BoNT injections was 10.8 ± 6.9 years. The dose of BoNT was also adjusted at each visit based on patients' previous response. The average dose of onabotulinumtoxin-A per visit in the 12 months prior to participating in the study was 53.4 ± 25.6 units (range, 16.5 – 92 units) (Table 1). Flexor digitorum superficialis (FDS), flexor pollicis brevis (FPB) and flexor pollicis longus (FPL) were the most commonly injected. During the evolution of patients' symptoms, BoNT injections were modified to achieve maximum relief. Thus, injected muscles during the first visit and the prior 12 months were different.

Targeted muscles at the initial BoNT injection visit of patients with WC mostly included flexor muscles, such as FDS, flexor carpi radialis (FCR), FPB, and FPL muscles except for patient 4, in whom targeted muscles were all extensors, i.e., extensor digitorum communis (EDC) and extensor pollicis brevis (EPB) muscles. For patients 5 and 6, targeted muscles at initial visit included a combination of flexors and extensors. Twelve months prior to participation, the targeted muscle patterns slightly changed but mostly to include flexor muscles. Patient 5 remained the only patient where extensor muscles, i.e., EDC and extensor digiti minimi (EDM) muscles, were the main targets. The main flexor muscles targeted in the prior 12 months were the flexor digitorum profundus (FDP), FCR, FPL and FDS muscles (Table 2).

The mean active ROMs of patients with WC and HVs are summarized in Table 3. Only 5 of 38 measurements were significantly different between the patients with WC and HVs. Active ROMs for extension of D1 MCP joint and flexion of D2 and D5 MCP joints were significantly limited in patients (ROMs were 12, 16, and 14 degrees with p-values of 0.017, 0.049, and 0.041, respectively). Active ROMs for extension of D3 and D5 DIP joints were significantly excessive in patients (ROMs were 7 and 6 degrees with p-value of 0.025 and 0.017, respectively) compared with HVs. The other active ROMs did not show any important differences.

The Spearman correlation coefficient analysis showed that active ROMs for flexion of D2 MCP joint significantly inversely correlated with the disease duration ($r = -0.76$, $p = 0.049$), and DDS-handwriting sub-score ($r = -0.79$, $p = 0.049$) (Figure 1A and 1B, respectively).

4. Discussion

Our aim was to define the role of biomechanical properties of the hands and arms of patients with WC. This study showed that active ROMs for extension of D1 MCP joint and flexion of D2 and D5 MCP joints were reduced in patients with WC, but active ROMs for extension of D3 and D5 DIP joints were greater in patients with WC than HVs. This study also showed significantly negative correlation between active ROMs for flexion of D2 MCP joint and duration of WC and DDS-handwriting sub-score.

The significant differences of hand joint movements between patients with WC and HVs might be explained by joint abnormality, co-contraction of the antagonist muscles acting on the joint or changes in muscle properties such as muscle atrophy. For joint abnormality, all participants in this study did not have apparent structural joint deformity or overt contracture; however, we did not examine passive ROM. Some previous studies of patients with musician's dystonia have found limitations of passive range [17,18]. Some dystonia patients have co-contraction of the antagonist muscles in the affected body part that might restrict active joint movement. This could be studied in the future with electromyography. Another possibility is that cumulative, long-term effects of BoNT might change muscle properties leading to muscle atrophy and mild muscle weakness that could not be detected by the usual neurological examination. Informal visual inspection suggested that most of our patients developed some atrophy, but, as noted, without apparent motor weakness. Additionally, atrophy might not only be attributed to BoNT injections, but also to muscle disuse as these patients develop compensatory movements to avoid triggering the dystonia. Below these considerations are addressed specifically with regards to our findings.

Flexion of MCP joints of D2 to D5 is controlled by the action of the lumbrical muscles with some contribution from the FDS. The extension of MCP joints of D2 to D5 uses extensor indicis proprius (EIP), EDC and EDM muscles. Flexion of the DIP joints of D2 to D5 is controlled by the action of the FDP. Most of our patients presented with a hyperflexion pattern of their digits. As a result, the flexor muscle group (specifically FDS and FDP muscles) was repetitively injected. Hence, subclinical motor weakness and atrophy of the flexor muscles secondary to repetitive injection plus the effect of co-contraction of EDC and EDM may have contributed to limitation of flexion at the MCP joint of D2 and D5 in our

patients. While extension of MCP joint is produced by an action of EIP, EDC, and EDM, extension of PIP and DIP joints are produced by the action of interosseous muscles. Therefore, mild degree of weakness of flexor muscles due to repetitive BoNT injection with the effect of co-contraction of interosseous muscles may explain the findings of the greater range of extension at DIP joint of D3 and D5 in patients with WC.

The FPB muscle contributes to D1 flexion at MCP joint while the EPB muscle contributes to D1 extension at the same joint. D1 and D2 are essential digits that help individuals hold a pen and are necessary to write. These two digits are often affected in patients with WC. In this study, 5 of 8 patients (patients 3, 4, 6, 7 and 8) had dystonic symptoms ascribed to the FPB causing both D1 abduction and flexion at the MCP joint. Therefore, excessive contraction of FPB in patients with WC may explain the limitation of thumb extension at the MCP joint. D2 flexion is also a major contributor to writing; as we expected, the results showed significantly inverse correlation between active ROM of flexion of D2 MCP joint and disease duration and DDS-handwriting sub-score. It may be that the abnormal flexion of D2 MCP joint developing over the period of repetitive long duration of writing (overuse) and the extent of ROM limitation also increased along with disease severity which was measured by DDS-handwriting sub-score. We did not find limitation of ROM at the wrist and elbow joints in any of the patients with WC.

The impact of focal dystonia on individual finger movements is not clear and has been a matter of debate. A study looking at MC revealed that pianists with affected D2 had stronger keystrokes than healthy pianists. However, keystrokes were slower in pianists with affected D3 and D4 fingers [23]. This indicates finger-specific loss of finger movement control in FHD patients. For dexterous use of the hand in specific tasks such as writing or playing musical instruments, independent finger control is crucial. In this study, we found specific patterns of decreased and increased active ROM. This demonstrates that these patients, when in baseline state, might have specific deficits of movement that could influence their motor control. Such deficits in ROM can lead to central nervous system changes [16]. We hypothesize that the peripheral biomechanical component of joints may in fact contribute to the pathophysiology of WC in part by altering the sensory input and distortion of the sensorimotor integration leading to abnormal posturing [16]. Therefore, correcting the biomechanical abnormalities with repetitive practicing may re-adjust the sensory input and then restore sensorimotor integration that would potentially lead to improvement of hand function. Supportive evidence of this hypothesis has been presented in previous studies. Zeuner and colleagues showed that immobilization followed by specific and non-specific motor re-training in patients with WC improved affected hand functions evaluated by WCRS and DDS at 4 and 8 weeks compared with baseline [26]. Singam and colleagues showed that practicing with a writing orthotic device for 2 weeks improved hand function evaluated by WCRS in patients with WC [27].

A possible explanation for why using orthotic devices or differently shaped pens may improve handwriting is task switching. The posture and movement of the hand while writing are produced by a specific set of motor programs in the brain. If these programs malfunction, by loss of inhibition, abnormal synaptic plasticity, and abnormal sensory input along with genetic predisposition, WC may develop. Orthotic devices or variation in pen

shape improve writing by changing the specific motor program by modifying the angle of hand and/or selecting the different muscles for holding the devices, and shifting the movement from distal (e.g., hand or wrist) to proximal (e.g., elbow or shoulder) muscles while writing. Chemodenervating agents such as lidocaine or BoNT weaken dystonic muscles and improve hand function by re-adjusting sensory input to restore sensorimotor integration within the primary motor and sensory cortices [28] leading central plasticity.

As this study was exploratory, the results lead to hypotheses that can be tested in future larger appropriately powered studies. Passive as well as active ROM should be evaluated in future studies.

5. Conclusions

This exploratory study showed abnormalities of active biomechanical hand properties; these may partly contribute to the pathophysiology of WC. The differences in the active ROM of D2 MCP flexion in patients with WC (compared with HVs) negatively correlated with both disease severity and duration. These findings may result from a combination of various factors including limitation of joint mobility, co-contraction of opposing muscles, and subclinical muscle weakness and atrophy secondary to cumulative therapeutic BoNT injections. Future studies involving a larger number of participants may show a more robust significant role of abnormal biomechanical properties of the hand in the pathophysiology of WC.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Roles of the authors

Prachaya Srivanitchapoom collected the data, performed data analysis, prepared the first draft of manuscript, and reviewed and critiqued the manuscript.

Ejaz A. Shamim conceptualization of study protocol, data collection, data analysis, and reviewed and critiqued the manuscript.

Pierre Diomi wrote the study protocol, collected the data, analysed the data and prepared the first draft of manuscript.

Takaaki Hattori, Sanjay Pandey, and Jung E. Park edited, reviewed, and critiqued this manuscript.

Tianxia Wu and Sungyoung Auh, the statistical consultants, selected the statistical analysis method and performed these analyses.

Mark Hallett conceptualized the study protocol, and revised the manuscript for intellectual content

Highlights

- Peripheral mechanisms, as well as central mechanisms, might contribute to pathophysiology of WC
- Abnormal range of motion of joints in the affected hand were found in patients with WC
- Index finger flexion showed negative correlation to disease duration and severity
- Hand biomechanical properties should not be ignored in the pathophysiology of WC

Figure 1. Linear correlation between the range of motion of flexion of metacarpophalangeal joint of index finger and the disease duration and disease severity

(A) Abnormal ROM of flexion MCP joint of D2 (degree in the x-axis) was inversely correlated with disease duration ($r=-0.76$; $p=0.049$) and (B) was also inversely correlated with disease severity ($r=-0.79$; $p=0.049$). ROM = Range of motion; D2 = Index finger; MCP = Metacarpophalangeal; WC = Writer's cramp; and DDS = Dystonia disability scale

Table 1

Demographic and clinical data of subjects.

Subjects	Age (Years)	Sex	Dominant hand	Affected hand	Duration of WC (Years)	Pattern of WC	Number of BoNT injection (Visits)	Duration of BoNT injection (Years)	Average dosage of BoNT per each visit in the past 12 months (Units)	DDS – Handwriting
WC1	53	F	R	R	16	Flexion	21	9	27.5	1
WC2	56	M	R	R	13	Flexion	24	7	60	1
WC3	70	F	L	L	20	Flexion	45	19	92	3
WC4	70	F	R	R	24	Flexion	39	13	42.5	2
WC5	48	M	R	R	19	Extension	32	12	45	2
WC6	57	F	R	R	12	Flexion	5	1	16.5	0
WC7	65	M	R	R	30	Flexion	35	21	64	3
WC8	55	M	R	R	19	Flexion	5	4	80	2
HV1	47	M	R							
HV2	55	F	R							
HV3	54	M	R							
HV4	53	F	R							
HV5	68	M	L							
HV6	68	F	R							
HV7	65	F	R							
HV8	52	F	R							

WC = Writer's cramp; HV = Healthy volunteer; BoNT = Botulinum neurotoxin; F = Female; M = Male; R = Right; L = Left; and DDS-Handwriting = Dystonia Disability Scale – Handwriting sub-score: this score is ranged from 0 (normal) to 4 (unable to grasp to maintain hold on pen).

Table 2

Injected muscles with botulinum neurotoxin at clinical visits

Subjects	Affected side	Visit	Targeted muscles
WC1	R	First visit Past 12 months	FDS 2,4 and FPL EPL and FDS 2,3,4,5
WC2	R	First visit Past 12 months	FCR, FDS 2, FPB and FPL FCR and FDS 2,3
WC3	L	First visit Past 12 months	FDS 2,3, FPB and FPL FCR, FDP 2, FPB, FPL and Trapezius
WC4	R	First visit Past 12 months	EDC and EPB FDP 2, FDS 2, FPB and FPL
WC5	R	First visit Past 12 months	FCR, EDC, ECU, EPB and EPL EDC 2,3, EDM, ECU and Lumbrical 2,3
WC6	R	First visit Past 12 months	FDP 4,5, EPL, EIP and Pronator FDS 3,4, FDP 4,5, FPB and EIP
WC7	R	First visit Past 12 months [*]	FCR, FDS, FPB and FPL FCU, FDS 2,3,4,5, FPB, FPL and Supinator
WC8	R	First visit Past 12 months [*]	FDS 2,3,4, FDP 2,3,4, FPB and FPL FDS 2,3,4, FDP 2,3,4,5, FPB and FPL

^{*} = 18 months prior to time of enrollment.

WC = Writer's cramp; R = Right; L = Left; FCR = Flexor carpi radialis; FCU = Flexor carpi ulnaris; FDS = Flexor digitorum superficialis; FDP = Flexor digitorum profundus; FPB = Flexor pollicis brevis; FPL = Flexor pollicis longus; ECU = Extensor carpi communis; EDC = Extensor digitorum communis; EDM = Extensor digiti minimi; EIP = Extensor indicis propius; and EPL = Extensor pollicis longus

Table 3

Subjects mean range of motions

Body parts	Motion	Range of motion (Degree)			p value
		WC (n=8)	HV (n=8)	Mean±SD	
Elbow	Flexion	139.9 ± 7.8	139.1 ± 6.3	0.835	
	Extension	1.9 ± 1.7	3.6 ± 2.2	0.099	
	Pronation	73.5 ± 7.9	74.5 ± 7.0	0.792	
	Supination	70.8 ± 6.5	75 ± 6.8	0.223	
Wrist	Flexion	83.1 ± 7.9	80.5 ± 6.6	0.482	
	Extension	52.4 ± 9.5	55.4 ± 7.8	0.501	
	Pronation	30.1 ± 5.9	27.9 ± 7.5	0.517	
	Supination	46.6 ± 10.4	44.3 ± 6.1	0.586	
Thumb (D1)	Flexion	13.8 ± 6.7	19.8 ± 8.5	0.138	
	Extension	14.5 ± 8.5	17.1 ± 5.4	0.473	
	Flexion	43.4 ± 10.5	48.3 ± 8.3	0.319	
MCP	Extension	16.1 ± 8.9	28.3 ± 9.1	0.017 *	
	Flexion	62.0 ± 14.9	69.6 ± 10.7	0.259	
	Extension	19.3 ± 9.2	29.1 ± 24.8	0.309	
Index finger (D2)	Flexion	60.9 ± 19.9	76.6 ± 5.9	0.049 *	
	Extension	19.3 ± 5.6	22.4 ± 8.1	0.386	
	Flexion	75.0 ± 20.4	93.9 ± 14.8	0.053	
PIP	Extension	13.5 ± 7.4	9.8 ± 7.0	0.316	
	Flexion	51.0 ± 19.9	54.0 ± 12.0	0.721	
	Extension	8.0 ± 6.7	7.4 ± 5.9	0.845	
DIP	Flexion	65.8 ± 22.0	76.0 ± 9.2	0.245	
	Extension	16.9 ± 8.5	13.9 ± 6.6	0.444	
	Flexion	77.8 ± 25.1	89.3 ± 19.3	0.321	
MCP	Extension	16.3 ± 7.6	12.1 ± 7.5	0.293	
	Flexion	56.8 ± 24.4	56.5 ± 12.6	0.979	
	Extension	13.9 ± 6.4	6.9 ± 4.7	0.025 *	

Body parts	Motion	Range of motion (Degree)		p value
		WC (n=8)	HV (n=8)	
Ring finger (D4)	MCP	67.4 ± 20.9	64.1 ± 18.0	0.744
	Flexion			
	Extension	15.9 ± 5.9	11.3 ± 7.5	0.191
	PIP	80.5 ± 18.4	92.1 ± 15.5	0.193
Middle finger (D4)	PIP	13.0 ± 6.5	9.0 ± 5.0	0.191
	Extension			
	DIP	47.4 ± 27.3	47.0 ± 10.5	0.972
	Flexion	7.3 ± 4.3	4.9 ± 3.18	0.229
Little finger (D5)	Extension			
	MCP	70.8 ± 16.0	84.5 ± 6.5	0.041 *
	Flexion			
	Extension	18.9 ± 10.4	20.1 ± 11.1	0.819
Ring finger (D4)	PIP	76.1 ± 20.7	86.4 ± 19.6	0.326
	Flexion			
	Extension	13.9 ± 10.1	6.4 ± 3.9	0.070
	DIP	56.8 ± 26.7	76.3 ± 13.5	0.088
Middle finger (D4)	Flexion			
	Extension	9.0 ± 4.9	3.1 ± 3.7	0.017 *

* = Statistical significant $p < 0.05$.

WC = Writer's cramp; HV = Healthy volunteer; CMC = Carpometacarpal; MCP = Metacarpophalangeal; PIP = Proximal interphalangeal; DIP = Distal interphalangeal; and SD = Standard deviation.