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Published in:
The Clinical Journal of Pain

DOI (link to publication from Publisher):
10.1097/AJP.0000000000000596

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Mista, C. A., Monterde, S., Inglés, M., Salvat, I., & Graven-Nielsen, T. (2018). Reorganized Force Control in Elbow Pain Patients During Isometric Wrist Extension. *The Clinical Journal of Pain*, *34*(8), 732–738. https://doi.org/10.1097/AJP.0000000000000596

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The Clinical Journal of Pain Publish Ahead of Print
DOI:10.1097/AJP.0000000000000596

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REORGANISED FORCE CONTROL IN ELBOW PAIN PATIENTS DURING ISOMETRIC WRIST EXTENSION

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Original paper for: Clinical J Pain

Running title: *Reorganised force control in elbow pain patients during isometric wrist extension*

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ABSTRACT

INTRODUCTION: Reorganised force control may be an important adaptation following painful traumas. In this study, force control adaptations were assessed in elbow pain patients. Increasing the contraction demand may overcome pain interference on the motor control and as such act as an internal control. It was hypothesized that elbow pain patients compared with control subjects would present greater change in the direction of force when increasing the demand of the motor task.

METHODS: Elbow pain patients (n=19) and healthy subjects (n=21) performed isometric wrist extensions at 5-70% of maximum voluntary contraction. Pressure pain thresholds were recorded at the lateral epicondyle and tibialis anterior muscle. Contraction force was recorded using a three-directional force transducer. Participants performed contractions according with visual feedback of the task-related force intensity (main direction of wrist extension) and another set of contractions with feedback of the three force directions. Going from the simple to the detailed force feedback will increase the demand of the motor task. Force steadiness in all 3 dimensions and force direction was extracted.

RESULTS: Compared with controls, elbow pain patients presented lower pressure pain thresholds at both sites ($P<0.05$). Force steadiness was not significantly different between groups or feedback methods. The change in force direction when providing simple visual feedback in contrast to feedback of all force components at all contraction levels was greater for patients compared with controls ($P<0.05$).

CONCLUSION: The larger change in force direction in pain patients implies redistribution of loads across the arm as an associated effect of pain.

Keywords (5 maximum): elbow pain, isometric force, sensory-motor control, lateral epicondylalgia.

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INTRODUCTION

Chronic elbow pain is one of the most frequent reported location of pain, involving around 1-3 % of the population.[1] According to previous statistics, elbow pain is recognized as a prevalent work-related musculoskeletal disorder caused by different factors including repetitive work (91%), biomechanical factors (6 %), work posture (1 %) and mechanical vibrations (1 %).[2] It has been estimated that around fifty percentage of employees who perform repetitive tasks are prone to suffer a muscle injury.[3–5] The dominant arm is primarily affected by chronic elbow pain, and this condition is associated with poorly designed occupational frameworks.[6] In most of the cases, chronic elbow pain is accompanied with tenderness during palpation, and eventually pain with resisted wrist or finger movement.[7] Undoubtedly, chronic elbow pain represents a great challenge to the motor control and thus quality of performed tasks.[8]

Chronic elbow pain patients exhibit reduced strength in different motor tasks including grip and wrist extension/flexion.[9,10] In particular, lateral epicondylalgia patients present reduced extensor carpi radialis muscle activity,[11] and weakness in some of the elbow and shoulder muscles.[8,11] In addition to the force reduction, these patients commonly have active myofascial trigger points in the forearm muscles,[12] which presumably increase pain sensitivity and affect the muscle synergies during a movement. This alteration of the limb kinetic may impact on the activity and coordination of the muscles involved in function of the wrist joint. Hence, force strength may not be sufficient to assess important aspect of the effects of elbow pain on the motor control.

Several studies have demonstrated that short-term experimental muscle pain reduce force steadiness[13,14] and induce reorientation of the net force in healthy subjects.[15,16] These changes in the force output may be associated with decreased proprioception in the wrist joint, which is also observed in chronic elbow pain patients.[17] Restraining the freedom of the contractions, i.e. by increasing the information in the visual feedback, it is possible to compensate potential decreased in proprioception caused by muscle pain.[16] Interestingly, sustained experimental elbow pain, elicited by intramuscular injection of nerve growth factor into the extensor carpi radialis brevis muscle, induce a reorientation of the force rather than a change in the force steadiness during a isometric contraction.[18] These characteristics of the force, steadiness and direction, could facilitate the development of new tools for assessment of manifestations in chronic elbow pain. However, there is no evidence about the effects of chronic elbow pain on the force control during isometric wrist extension.

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The present study investigates the effect of chronic elbow pain on the motor control, focusing on force steadiness and direction of the force in isometric wrist contractions when going from simple feedback of force to 3-dimensional force feedback. It is hypothesized that chronic elbow pain induces reorganization of force direction rather than changes in force steadiness.

METHODS

Participants

Chronic elbow pain patients (n=19; 57 % women; 42 ± 10 years; pain Patient group) and sex and age matched healthy subjects (n=21; 55 % women; 36 ± 14 years; Control group) participated in the study (Fig. 1). Participants that exhibited musculoskeletal pain in the elbow region for more than 2 month were included in the Patient group. Healthy subjects were excluded if they presented pain in the lateral epicondyle region. Group size calculation was based on an estimated difference of 20% in main parameters (force steadiness), and on types I and II errors at 5% and 20%, respectively, requiring 15 subjects for each group when using paired comparisons. The experimental procedures were approved by the Clinical Research Ethical Committee of the IDIAP Jordi Gol i Gurina (Ref. No, 06-04-27/ 4proju) and the Hospital Universitari Joan XXIII (Ref. No, 52/ 2013).

Experimental protocol

Participants attended to a single session. Anthropometric data (weight and height), wrist passive range of motion, myofascial trigger points (MTrPs), and pressure pain thresholds (PPT) were assessed; pain and functional questionnaires were fulfilled. Participants sat upright in a chair with their back resting against a backrest. The shoulder was at 90 flexion degrees (Fig 2). Maximal voluntary wrist extension (MVC) was recorded by performing 3 consecutive maximal isometric wrist extension trials for 10 s with an interval of 30 s in-between. After a 120 s rest, two sets of isometric wrist extension were performed at 5, 30, 50, and 70% MVC in randomized order. The contraction consisted of a 5 s of ascending ramp, 10 s of steady phase, and a 5 s of descending ramp. Contraction force was recorded in the task-related (Fz) as well as tangential directions (Fy: wrist radial-ulnar deviation and Fx: longitudinal movement of the wrist) as shown in Figure 2. Force was presented in real-time by a dynamic circle on a computer screen, whereas the force target was represented by a moving square. The centre of the force target was represented by a black dot. Participants performed two set of contractions: 1) with visual feedback including the tangential force directions (Fy and Fx), and 2) with only the visual feedback of the task-related force (Fz).[16] Inclusion of tangential directions in the visual feedback

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impose restriction on the contraction and demand higher force precision. After a 60 s rest, maximum isometric gripping force was recorded with a handgrip dynamometer (SP-5030J1, JAMAR). Three gripping MVC were performed for 5 s with 90º shoulder flexion and elbow extended. Pain intensities during wrist extension and grip force were scored after each trial on a visual analogue scale (VAS) where 0 indicate 'no pain' and 10 'the worst pain imaginable'. Pain VAS scores of the maximal contractions were averaged between the trials.

Questionnaires and assessment of functional limitation

Disability of the Arm, Shoulder and Hand Questionnaire (DASH) in Spanish was used to assess upper-extremity disability: ranging from 0 (best functional state) to 100 (worst situation).[19] The Patient-rated Tennis Elbow Evaluation Questionnaire (PRTEE) was used to measure forearm pain and disability in the patients. The PRTEE is a 15-item questionnaire, and the task-related questions are scored in ranging from 0 (no pain and no functional disability) to 100 (worst imaginable pain with a very significant functional disability).[20,21] The Spanish translation of McGill Pain Questionnaire was used to describe the quality and intensity of subjective pain experienced.[22] Two indexes were calculated from McGill questionnaire: Pain Rating Index (PRI) and Present Pain Intensity (PPI). The PRI depicts the sensory and affective characteristics of pain measurement based on the ordinal value of the word chosen through 78 adjectives, and the PPI represents the pain intensity on a scale rating from 0, the better condition, to 5, the worst condition.[22] Active and passive range of wrist flexion and extension were measured.

Three-dimensional force recordings during contraction

Three-dimensional force was recorded using a six-axis load cell transducer (MC3A 250, AMTI, USA) with high sensitivity (0.054, 0.054, 0.0134 V/N for Fx, Fy, Fz; and 2.744, 2.744, 2.124 V/Nm for Mx, My, Mz). The analogue output of the transducer was amplified, and low-pass filtered at 1 kHz (MSA-6, AMTI, USA). The force signals were sampled at 2 kHz and stored after 12 bits A/D conversion.

Force recordings were digitally low-pass filtered at 20 Hz using a second order Butterworth filter. The analysis was performed in the steady period of the contractions (2-8 s). Standard deviation was used to quantify force steadiness (FSD) in the task-related direction. The Centroid Position Difference (CPD) index was used to quantify change of force direction between the two set of contractions with different feedback conditions.[16,23] The CPD is calculated from a two-dimensional histogram (5 x 5 bins) representing the range of the Fy (wrist radial-ulnar deviation) and Fx (longitudinal movement of the wrist)

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direction. Coordinates of the centre of gravity were extracted from the histograms for each set of contractions, and absolute difference between centroids was computed for each direction. In the present study, the CPD values were calculated contrasting the force recordings during the feedbacks with and without including the information of the tangential force directions, obtaining two values: 1) CPD in the longitudinal movement of the wrist (Fx direction), and 2) CPD in the wrist radial-ulnar deviation (Fy direction).[16] In addition, force error sum of squares (SSE) was computed at each force level as the difference between the force target and the force measured in the task-related force.

Pressure algometry and myofascial trigger point examination

A handheld electronic pressure algometer (Ten™ FDX 50, Wagner Instruments) with a 1-cm^2 circular probe was used to quantify PPT. The PPT was assessed over lateral epicondyle area and tibialis anterior muscle on the right leg as a control outlying site (5 cm lateral to the tibial tuberosity, in the upper one-third of the muscle belly).[24] The location for each measure was alternated, and the procedure was repeated 3 times at 30-s intervals. Average of the PPT values was used for further analysis.

The total number of active and latent MTrPs was assessed on the extensor carpi radialis brevis, extensor carpi radialis longus, and extensor digitorum communis muscles. The procedure was performed according to established criteria for MTrPs examination.[25,26] An active MTrP was defined by the presence of a taut muscle band, local twitch response, and most tender spot upon digital palpation generating spontaneous and familiar referred pain. Latent MTrP shared the same inclusion criteria except that the referred pain, if occur, was unfamiliar.[27]

Statistical analysis

Data are presented as mean values and standard deviation throughout the text. Normal distribution was tested using Kolmogorov-Smirnov test. Two-sided independent-samples t-tests were used to compare group differences for age, weight, height, PPT, grip force, and MVC. Data not normally distributed including DASH, PRTEE, McGill, wrist MVC and grip VAS scores, and number of MTrPs between groups were tested using Mann-Whitney U test. Chi-square test was performed to assess gender distribution.

To test whether elbow pain affects force characteristics, a mixed-model analysis of variance (ANOVA) model were applied to FSD (steadiness), force SSE (force error), and CPD (direction of force) with *group* (pain patient or control) as a between-subject factor and *contraction level* (5%, 30%, 50%, 70% of the MVC force) as a within-subjects factor. A similar ANOVA model was used to test whether wrist VAS scores changed across

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groups and level of contractions. In case of significant main effects or interactions the Newman–Keuls (NK) post-hoc tests were applied correcting for multiple comparisons. P-values less than 0.05 were regarded as significant.

RESULTS

Self-reported pain and assessment of arm functionality

Gender, age, weight, height, dominant arm, or wrist range of motion were not significantly different between groups. Within the Patient group, 79% presented the dominant arm affected (n=15), whereas 21% showed pain in the non-dominant arm (n=4). The patients reported higher PRTEE, DASH, and McGill compared with Control group (Table 1).

Pressure pain thresholds and trigger point assessment

The patients showed lower PPTs in the elbow region and at the tibialis anterior muscle (Table 1, t_{40}=-6.17, P<0.05) compared with the Control group. Active MTrPs were found only in patients (Patient: 1.32 ± 1.60 vs Control: 0 ± 0; U=90, P<0.001). Latent MTrPs were presented in both groups, although the Patient group presented higher number of latent MTrPs compared to Control group (U=95.5, P=0.008; Table 1).

Force strength and contraction-induced pain

The Patient group showed reduced MVC during wrist extension force (Patient: 4.6 ± 1.8 N/cm vs Control: 5.9 ± 1.9 N/cm; t_{36} =2.2, P=0.03) and higher pain VAS scores during wrist MVC compared with the Control group (Patient: 5.2 ± 2.5 cm vs Control: 0.1 ± 0.4 cm; U=4, P<0.001). There was no statistical difference in maximal grip force in the patients compared with the Control group (Patient: 27.3 ± 11.6 Kg vs Control: 34.1 ± 11.3 Kg; t_{38}=-1.88, P=0.068) and the Patient group reported greater pain VAS during grip force assessment (Patient: 4.3 ± 3.2 cm vs Control: 0.1 ± 0.4 cm; U=45, P<0.001).

Force steadiness and direction during wrist extension

There were no significant differences in FSD nor in the SSE, between patients and controls (Fig 3). However, greater changes in the direction of the force were found between groups in the longitudinal movement of the wrist direction (Fx; Fig 4; CPD_x Patient: 2.91 ± 0.03 vs Control: 3.04 ± 0.03; ANOVA: $F_{1,37}$ =6.81, P=0.01). The post-hoc analysis revealed higher CPD in the Patient group compared with Control group (NK: P<0.05). This result reflects a greater reorganization of direction of the force between submaximal contractions in the Patient group caused by an increasing demand of force control required by changing in the visual feedback. A significant interaction between group and contraction *level* (ANOVA: $F_{3,111}$ =45.75, P<0.001) was found for pain VAS scored during the submaximal wrist extensions (Table 2). Patients reported higher VAS scores during 30, 50, and 70%

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MVC compared with the 5% MVC (NK: $P<0.05$), and for all contraction levels when compared with the Control group (NK: $P<0.05$).

DISCUSSION

This study demonstrates the force control reorganization in chronic elbow pain patients. The patients presented a reduction of muscle strength and had a larger change in direction of the force when increasing the demand of the force task (from excluding to including tangential force information) in comparison with the asymptomatic participants (Control group), which implies that chronic pain impairs the force control. However, although the patients generated lower intensity of wrist maximal extension effort, not all the force characteristics results significantly affected by chronic pain, since force steadiness was not different compared to the Control group. The force reorganization found in the chronic patients is consistent with the pain assessment results. The patients had lower pressure-pain threshold on the elbow region, higher arm functional disability, and greater pain during the motor tasks, as compared with the Control group. These findings suggest that chronic elbow pain alters the motor strategy, rather than the force precision.

Chronic elbow pain

The reduced PPT found on the epicondyle and tibialis anterior areas indicate widespread hypersensitivity in the elbow pain patients. Such widespread hypersensitivity has been previously associated with chronic musculoskeletal pain.[10,24] In chronic lateral epicondylalgia, patients present longer pain duration and widespread pain during acute experimental muscle pain compared with healthy subjects,[28] and also have reduced threshold for nociceptive flexion reflex, suggesting spinal cord hyperexcitability.[29] Taken together, facilitated central mechanisms is likely in chronic elbow pain patients.

Another phenomenon observed in the present study is the higher number of active and latent MTrPs in the extensor muscles in patients compared with asymptomatic participants. These MTrPs may cause an unbalance between muscle activation, increasing antagonistic muscle activities and overloading muscle fibres in synergists muscles.[30,31] It has been proposed that chronic pain distort the body image, by affecting the proprioception, exteroception, and interoception information[32] which may affect the motor strategy used by the patients.[33]

Peripheral sensitization mechanisms have also been associated with chronic elbow pain. For instance, in lateral epicondylalgia, changes in the connective tissue has been observed in chronic stages.[34,35] This degeneration seems to cause a reduction in proprioception,[36] which might affect the force control of chronic pain patients. In the

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current study, the patients showed distorted estimation of the developed force. Likewise, chronic low-back pain patients have shown reduced proprioception, and it has been suggested that reweighting the proprioceptive inputs from different parts of the body might counteract the localized reduction of proprioception.[37]

Effect of chronic elbow pain on the force and functionality

Chronic elbow pain represents a great challenge to the motor control. One of the changes observed in patients is the decreased of maximal force capability, which might be associated to several causes. For instance, it could be related to inhibitory effects of pain, or to a peripheral effect due to long inactivity of the muscles. Another possibility is that patients spontaneously adopt a non-optimal position during the maximal tests. Lateral epicondylalgia patients are prone to flex the wrist during gripping test.[38] Even though participants were guided and visually inspected during the maximal task in the experiment, slight changes in the position of the wrist might have occurred as result of a consolidated adaptation in patients, affecting the outcome of the maximal effort test. It is worth to note that force weakness may play a major role in the muscle imbalance of forearm muscles and, consequently, in the arm functionality[11] as also observed in the arm functionality questionnaires in the current study.

In contrast to reduction of maximal effort, there were no significant differences between groups for steadiness and error of the force. These results concur with previous findings showing that force steadiness is reduced during acute pain, associated with search for a potential beneficial motor strategy, whereas when pain is persisted and a new strategy is found, force steadiness is increased around the new solution.[18] It has previously been found that short-term muscle pain in the elbow region can cause a decreased force steadiness in isometric wrist extension.[18] However, the effect of chronic elbow pain on force steadiness has not been studied before. In other chronic pain conditions, several studies have shown unchanged force steadiness. For example, force steadiness is unaffected for subacromial impingement syndrome patients when performing isometric shoulder abduction,[39] and similar results are observed for low-back patients during control of their upright trunk posture.[40]

The key finding of the present study is that chronic elbow pain patients presented greater changes of the direction of the force compared with asymptomatic subjects, when changing the demand of the motor task. In other words, patients under pain have higher reorganization between two strategies used when performing motor tasks with different demands. There are several mechanisms that could account for the reorientation of the

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force. First, muscle pain can induce non-uniform activity in the motor unit population and, consequently, alter the direction of the force.[15] Second, the presence of MTrPs itself can affect the direction of the force. These discrete hardness points, localized within region of the muscle, may impact on the capability of force development of muscle fibres, causing a diminishing contribution of functional sarcomeres acting in a particular force direction.[25,41]

The results could be consider from the contemporary theory of pain effects on the motor control, which propose that changes in strategies to perform a motor task facilitate redistribution of loads across the involved structures, and this protects the system in the short-term, although it may have deleterious effects on the long-term due to overloading of some healthy structures.[42] The patients involved in the present study most likely were in the later stages of the motor adaptations, i.e., where motor adaptations are consolidated. Nevertheless, it is clear that the strategies used by patients to achieve each task were different when increasing the demand, even though they reported pain in both motor tasks. It has been suggested that the system used a consolidate strategy to resolve a familiar motor task, but when the demand is increased and the strategy is no longer convenient, a new strategy may be required.[33] Most likely, the central nervous system would try to preserve a consolidated strategy to resolve the motor task whenever is convenient, even though the strategy might not be the optimal solution.

Implications of the results for physical treatment

Conventional treatments for chronic elbow pain, such as lateral epicondylalgia, are based on the restoration of muscle balance and pain relief of the arm.[43] The most effective therapeutic programs include concentric[44] and/or eccentric exercise,[45] resulting in strengthening of extensor muscles of wrist and hand, which is essential for obtaining the best outcome.[43,46,47] However, the design and follow-up of patients during the treatments rely on subjective feedback, generally consisting of the description of pain and functional limitations of the patients. The implications of results from the present study are twofold. First, treatments for chronic elbow pain should target the central levels, i.e., target the relearning of the optimal motor strategy. In this regard, chronic low back pain patients have shown to achieve the same accuracy as the asymptomatic subjects when sufficient learning period of a motor task is provided.[48] Second, changing the demand between two isometric force tasks, and assessing the variation of the direction of the force, could serve as an objective index to assess effectiveness of different treatments, as the increased in the reorientation of the force could be directly associated with worst imbalance of the muscle activity.

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The implications of the current study might not be extended to all chronic conditions because the population were elbow pain patients, although it is unknown if other pain conditions would reproduce the same pain pattern. Another potential limitation presented is that examination of pain threshold and myofascial pain syndrome before the force assessment may conditioning the motor performance, due to pain caused by the assessments.

CONCLUSION

The current study shows that changing the demand of the visual feedback during isometric wrist extensions resulted in greater reorientation of the force in the chronic pain elbow patients. On the contrary, alteration of force steadiness seems to lack relevance in chronic elbow pain condition.

CONFLICT OF INTEREST

None declared

ACKNOWLEDGEMENT

Center for Neuroplasticity and Pain (CNAP) is supported by the Danish National Research Foundation (DNRF121).

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TABLE LEGENDS

Table 1. Descriptive data of participants, pain and functionality test.

Table 2. Mean (SD) VAS scores after isometric wrist extension.

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FIGURE LEGENDS

Fig. 1. Time course and flow-diagram of participants.

Fig. 2. Experimental setup. Force was recorded in task-related (Fz) and tangential (Fy: wrist radial-ulnar deviation and Fx: longitudinal movement of the wrist) directions using a three-dimensional force transducer.

Fig. 3. Mean (SD) of force error sum of squares (ESS) and standard deviation of the task-related force (FSD) during the isometric wrist extensions. Both groups showed maximum error during the highest level of contraction (*, P<0.001). FSD was also increased monotonically for the level of contractions (**, P<0.05).

Fig. 4. Mean (SD) of distribution of centroids position difference (CPD) of the orthogonal axes: Fy (wrist radial-ulnar deviation) and Fx (longitudinal movement of the wrist). Data represent the change in the force direction when increasing the restriction of the force contraction (feedback of the task-related force versus feedback including the tangential force components). The Patient group showed a greater change in the direction of the force when changing the restriction of the contraction (*P<0.05).

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TABLES

Table 1.

	Patient Group (n=19)	**Control Group (n=21)**	**P-value**
Gender (male/female)	9/ 10	10 / 11	.99
Age, year	41 (11)	37 (13)	.29
Weight, kg	70.0 (16.4)	68.9 (12.5)	.81
Height, cm	166.3 (2.3)	161.5 (8.3)	.39
Dominant arm (left/right/ambidextrous)	16 / 0 / 3	19 / 2 / 0	.075
Active flexion, degrees	85.7 (20.8)	83.4 (21.7)	.79
Passive flexion, degrees	93.0 (21.2)	96.6 (11.7)	.73
Active extension, degrees	62.2 (21.1)	69.5 (12.6)	.33
Passive extension, degrees	68.2 (20.7)	78.1 (11.1)	.10
Epicondyle PPT, N	15.8 (8.7)	35.8 (11.5)	.000
Tibialis anterior PPT, N	57.4 (20.2)	71.5 (18.8)	.029
Active MTrPs	1.3 (1.6)	0.0 (0.0)	.005
Latent MTrPs	2.5 (1.1)	1.4 (1.2)	.008
McGill PRI (0-78)	25.4 (14.3)	0.00 (0.0-0.0)	.000
McGill PPI (0-5)	2.4 (0.6)	0.0 (0.0-0.0)	.000
PRTEE (0-100)	42.2 (18.5)	0.1 (0.5)	.000
DASH (0-100)	25.0 (15.6)	0.7 (2.4)	.000

Values are mean (SD) except for gender and dominant arm (n)

Abbreviations; PRI: Pain rating index; PPI: Present Pain intensity; PR TEE: The patient-rated Tennis Elbow Evaluation Questionnaire; DASH:The Disabilities of the Arm, Shoulder and Hand.

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Table 2.

	5% MVC	30% MVC	50% MVC	70% MVC
Patient Group (n=19)	0.8 (0,2)	1.7 (0,4)	4.7 (0,4)	6.2 (0,4)
Control Group (n=21)	0,0 (0,2)	0,0 (0,4)	0,0 (0,4)	0,2 (0,4)

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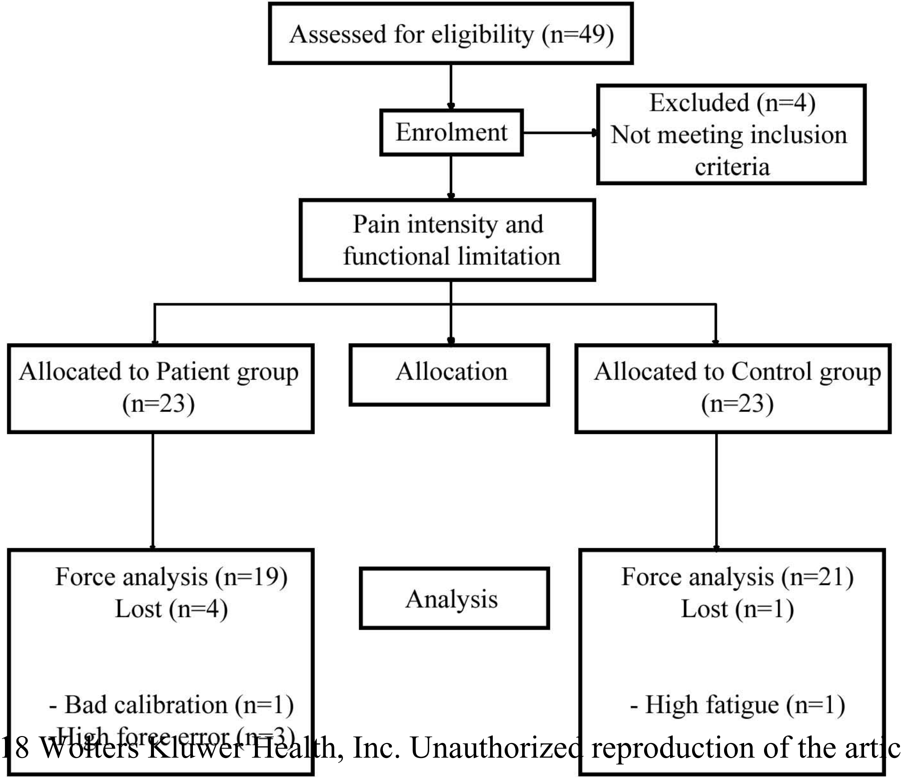

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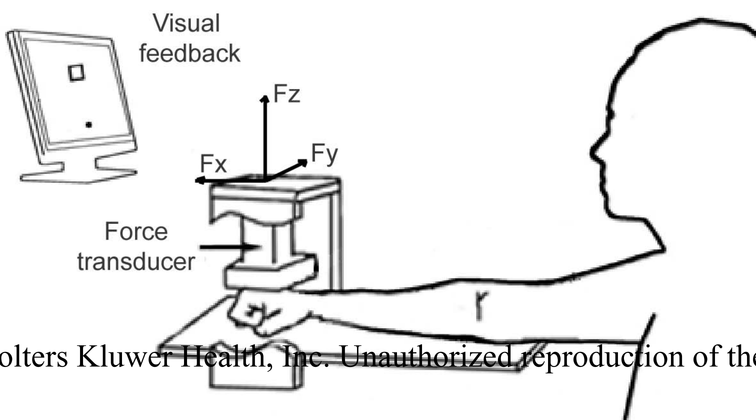

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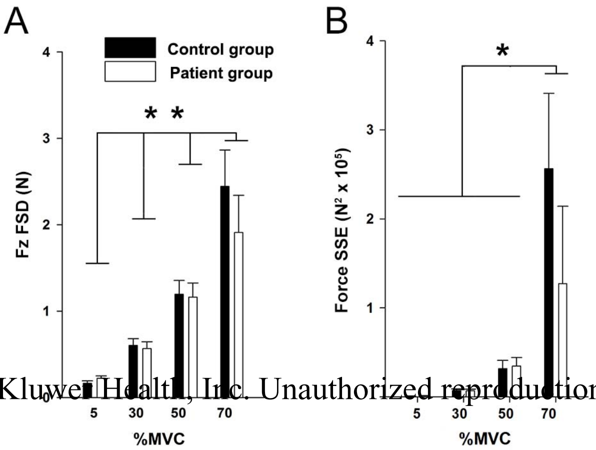

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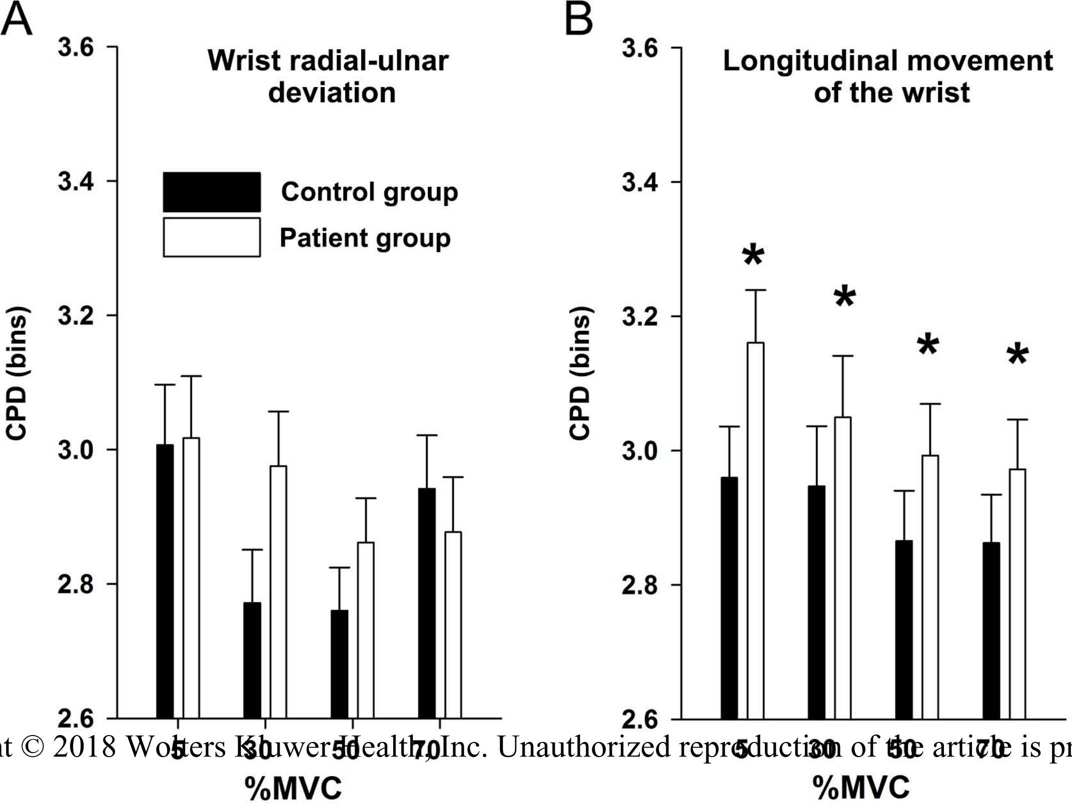

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