Title: LOWER ARM AND HAND MUSCLES IN FOCAL DYSTONIAS - SOME ANATOMICAL AND THERAPEUTIC ASPECTS

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Issue Date: 2008

Publisher: Saint-Petersburg State Polytechnical University,

Citation: Varzin, S.A. & Taraskovskaya, O.Y. (Eds.) Transactions of the 3rd All-Russian Scientific Practical Conference with international participants “Health - the base of human potential: problems and ways to their solution”. November 25 - 27, 2008, Saint-Petersburg State Polytechnical University, Saint-Petersburg, Russia. p. 353-363.

Abstract: Computer simulation of normal goal-oriented motion of human lower arm and hand may be also successfully applied in studying movement disorders, known as focal dystonias. Upper limb focal dystonia includes disturbed muscle tension balances, leading to painful, impaired and often aberrant motions. In their attempts to trace the backgrounds of this disorder, several authors have stressed the importance of the brain primary somatosensory cortex, and its role in brain-mapping. This turns out to be especially relevant during learning processes of new motor skills like practising by musicians. The present overview however will mainly analyse musculoskeletal mechanisms of arm and hand movements, with regard to their kinematics in repetitive motions. We will concentrate on pronation and supination movements of the lower arm during repeated shifting of the hand, as in handling a computer mouse, and focus on the maintaining of stable finger position during PC mouse scrolling. Physical therapy (PT) already proved itself useful in treating these focal dystonias, also known as repetitive strain injury (RSI). As an adjuvant to PT, we wish to propose local vibration therapies. Encouraging results of such a treatment, emanating from a recent pilot-study, are presented in conclusion.

ISBN: 978-5-7422-2020-6

Appears in Collections: Databases and Theoretical Computer Science Biomedical Research Institute (BIOMED) Functional Morphology
LOWER ARM AND HAND MUSCLES IN FOCAL DYSTONIAS - SOME ANATOMICAL AND THERAPEUTIC ASPECTS


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INTRODUCTION AND SUMMARY

Computer simulation of normal goal-oriented motion of human lower arm and hand may be also successfully applied in studying movement disorders, known as focal dystonias 1 - 3). Upper limb focal dystonia includes disturbed muscle tension balances, leading to painful, impaired and often aberrant motions. In their attempts to trace the backgrounds of this disorder, several authors have stressed the importance of the brain primary somatosensory cortex, and its role in brain-mapping 14). This turns out to be especially relevant during learning processes of new motor skills like practising by musicians 15, 22). The present overview however will mainly analyse musculoskeletal mechanisms of arm and hand movements, with regard to their kinematics in repetitive motions. We will concentrate on pronation and supination movements of the lower arm during repeated shifting of the hand, as in handling a computer mouse, and focus on the maintaining of stable finger position during PC mouse scrolling 23, 24). Physical therapy (PT) already proved itself useful in treating these focal dystonias, also known as repetitive strain injury (RSI) 24). As an adjuvant to PT, we wish to propose local vibration therapies 29). Encouraging results of such a treatment, emanating from a recent pilot-study, are presented in conclusion 31).
LOWER ARM - COMPARATIVE ANATOMICAL BACKGROUNDS

Locomotion in small arboreal quadrupeds that are generally regarded as precursors of lower primates includes rotational movements in shoulder, upper and lower arm, wrist and hand. A basic functional demand in those species is: keeping each hand alternatingly in contact with the substratum, while the body moves forward in the parasagittal plane. By this motion, the relative conservative feature of lateral rotation by the upper arm at the onset of each stance (to end up in a medial rotation at late stance) coincides with a decrease of crossing by the radius over the ulna, as long as propulsion stroke proceeds \(^4-6\).

In the opossum lower arm, this uncrossing or supination of the radius respective to the ulna is accentuated by a widening of the *spatium interosseum antebrachii*, as well as by early take-offs of the flexed 4\(^{th}\) and 5\(^{th}\) digits (Figure 1).

![Figure 1](image1.png) ![Figure 2](image2.png) ![Figure 3](image3.png)

Fig. 1 Walking opossum, top to base: propulsion includes lower arm supination
Fig. 2 Man, start propulsion stroke: medial rotation (arrow) of humerus (yellow)
Fig. 3 In propulsion: lateral rotation humerus, radius (red) crosses (*) ulna (blue)

In many primates including man, mainly as a consequence of the different positions of their shoulder blades, such rotational phenomena as the ones described above present themselves differently. Propulsion stroke by the arm, as long as the hand stays palm downwards in contact with the substratum, may show an increasing lateral rotation of the upper arm, while the radius gradually crosses the ulna \(^7-8\). The crossing itself is defined as pronation of the lower arm. Hereby the *spatium interosseum antebrachii* (seen from distally to proximally) becomes narrower, as the radius gradually overlaps the ulna (Figures 2 and 3).
LOWER ARM - THE SITUATION IN MODERN MAN

Quite comparable phenomena do occur when a seated person shifts his hand, palm downwards, to and from his body, e.g. by moving the computer mouse over a mouse-pad. By repeating these movements numerous times daily, the muscles of trunk, shoulder, upper and lower arm may start to display focal dystonia. In order to study one of the muscles that are possibly involved in developing such a dystonia, the pronator teres muscle was selected, based on its obvious capacity (just by muscle contraction) to move the radius over the ulna, thus narrowing *spatium interosseum antebrachii*, as a hallmark of pronation\(^{13}\).

Remarkably, a recent 2008 study on lower arm muscle activities while handling various types of PC mouse, left such actions of *m. pronator teres* out of consideration, although the various positions of lower arm pronation were taken into account\(^9\).

LOWER ARM - THEORETICAL KINEMATIC ANALYSIS

Anatomical and kinematic features of *m. pronator teres* were investigated theoretically, in human anatomical specimens by dissection, with use of magnifying loupes, and by roentgenphotogrammetry. In a small number (5) of anatomical specimens of the lower arm of otherwise normal subjects, as currently used during the practical courses of anatomy organized by our department, the pronator teres muscle was brought into view, and its various fibre bundles were carefully dissected\(^{11}\). The humeral head and the ulnar head of *m. pronator teres* fuse, after which their common tendon inserts on the *tuberositas pronatoria* of the radius (Figure 4). The precise position of pronator teres muscle was identified in anteroposterior radiographs, by means of lead markings attached to the various muscle fibre bundles prior to radiography (Figure 5). Pronator teres muscle was represented by straight lines between its markers, indicated on tracings of these radiographs (Figure 6). In each tracing, the average position of such lines representing the vector of *m. pronator teres* was introduced, to be used for a mathematical vector analysis of forces.

During pronation the radius approximately follows a conical path. The apex of this virtual cone is located at the head of the radius, while the centre of the circular base of this cone is the ulnar styloid process. The axis of this cone may be regarded as identical to the axis of forearm pronation and supination\(^{10}\). In the radiographs, the centre of the articular facet of the head of the radius, and the tip of the ulnar styloid process, served as the bony landmarks concerned. In the tracings the axes of pronation and supination were also introduced, by drawing a straight line connecting these two points.

A two-dimensional representation of this cone, which is an isosceles triangle, was used to introduce average pronator teres’ line of action (red, Fig.7)
at one slant side of this triangle, starting from the point representing *tuberositas pronatoria* of the radius in pronation. The direction of this vector was then used to estimate the muscle’s contribution to lower arm pronation (small green arrow, Figure 7). Mathematically, resolution of forces revealed - at least theoretically - that the effective contribution of *m. pronator teres* to forearm *pronation* constitutes about 25 % of its contribution to forearm *flexion* at the elbow \(^{12, 13}\).

The result of this analysis therefore suggests that, also in the *acquisition* of lower arm focal dystonia and repetitive strain injuries, pronator teres muscle might play only a minor role.

**Figure 4** Human lower arm: *m. pronator teres* (arrows) from humerus (yellow) and ulna (blue) inserts at radius (red) Brand-Hollister ('93) essentially adapted

**Figure 5** Arm anatomical specimen, X-ray, lead markers indicate *m. pronator teres*

**Figure 6** In positive, pro-supination-axis (red) and *m. pronator teres’* course added

**Figure 7** Triangle represents “pronation-path”, plus *m. pronator teres’* vector (red)
Experimental studies on the brain primary somatosensory cortex in primates, as related to repetitive strain injuries, have currently made use of the hands of a New World primate, Aotus in particular. With regard to the use of fingers in such cebid genera however, the next remarks should be kept in mind.

The fingers of most primates of the New World have a compact extensor assembly without such distinct distribution into bundles, as in higher primates, including man. This was demonstrated in the fingers of Callitrichidae and Cebidae, especially in Aotus (Figure 8). In these primates it was expected that, in proximal interphalangeal flexion, the lateral parts (l p, Fig. 8) of their compact extensor assembly would not be displaced palmarward as easily, respective to its medial part (m p, Fig. 8), as in higher primates including man. Absence of coupled interphalangeal flexion in some kinds of their grips would be the result.

In their behaviour, these New World primates including Aotus (i.e. the owl monkey) do show hand postures in which proximal interphalangeal flexion is coupled notably to distal interphalangeal extension or even hyperextension, leading to effective adhesive grips of the hands to large branches (Figure 9).

In prosimians too, the extensor assembly is compact. This supports the existence of a relationship between a simple structure of the extensor assembly and the prosimian-like nature of interphalangeal coupling.

**Figure 8**

![Figure 8](image)

**Figure 9**

![Figure 9](image)

**Fig. 8 Aotus finger transverse Ø at proximal interphalangeal (PIP)-level, see text**  
**Fig. 9 Aotus adhesive grip: distal interphalangeal (DIP)-extension & PIP-flexion**

**THE FREELY MOVING HUMAN FINGER**

A functional analysis of the human extensor assembly in relation to coupled interphalangeal motion was made by means of a kinematic model. In
this model, the two interphalangeal joints can be flexed simultaneously, as normally occurs in various types of grips and precision handling. A movie-sequence of simulation by mathematical modelling of such finger flexion was recently published. One initial frame from this sequence in particular is depicted in the diagram of the slightly bowed finger, in a stabilized position (Figure 10). Such stability of the freely moving finger is essential for finely tuned finger movements, e.g. by practising musicians. Any muscular imbalance may eventually lead to focal hand dystonia.

Apart from practising a musical instrument, finger scrolling while handling a computer mouse also requires such finger stability. Recent studies dedicated to mouse scrolling kinematics have underlined the importance of good muscular balances, for finger stability, as well as during finger mobility.

Fig. 10 Kinematic model: stable human finger in a slightly bowed position, lines representing tendons - extensor assembly distributed into separate bundles

THE FINGER IN NEUROPATHY - DIAGNOSTIC ASPECTS

Part of muscular imbalances in hand and finger may result from compression neuropathies in which one or more motor nerves are damaged, leading to paralysis of the muscles concerned. Apart from PC workers, professional musicians may be the subjects of such disorders. With regard to hand and fingers, a certain incoordination of interphalangeal motion may be present too, in such neuropathies.

To analyse the finger motor patterns before and after therapy, forward and reverse mathematical modelling, by means of the abovementioned kinematic finger model was successfully applied.

UPPER EXTREMITY REPETITIVE STRAIN INJURIES - THERAPEUTIC ASPECTS

To conclude, we wish to refer to a pilot study after the effects of vibration therapy on subjects suffering RSI symptoms of the upper extremity, in
comparison to classical rehabilitation therapy. 5 subjects in the control group underwent classical rehabilitation, 5 subjects in the experimental group received vibration therapy. A pre-post design was used to measure upper extremity movements for strength, and the McGill pain questionnaire for pain sensation. During 4 weeks, both groups received 8 sessions of therapy consisting of strength exercises. As a result, there was an average strength increase for both groups during the intervention. Indications of pain sensation decreased for both groups, though more significantly so for the group receiving vibration therapy. Vibration therapy can therefore be a significant adjunctive therapy for RSI.

In increasing strength and decreasing pain, it is more significant than classical rehabilitation \textsuperscript{29).}

**CONCLUDING REMARKS**

The present overview, highlighting some of the possible anatomical backgrounds of upper extremity repetitive strain injuries and dystonias, has left many questions unanswered. An obvious need is felt also, to gather data on a person’s ability to manage the relatively monotonous handling of a computer.

Such studies may advantageously include anatomical aspects, e.g. anthropometric measurements as well as highly sensitive registrations of finely tuned hand movements.

The abovementioned presentation clearly shows that until now, univocal explanations of mechanisms behind focal dystonias are hard to deliver. This is generally so in diagnostics, but also in pathophysiology and therapy. Thorough kinematical analyses might be able to unravel some of the enigmas still existing.

Recently, some doubt arose regarding the effectiveness of vibration therapies in systemic neuropathies \textsuperscript{30).} Nevertheless, strong indications currently exist that peripheral and local pain and muscular weakness can be effectively treated with the help of local vibration training, respectively by the application of electrovibrostimulation, preferably in a proper way, \textit{ad modum} Zinkovsky \textsuperscript{31).}

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