Elbow Muscular Relationships: An SEMG View of Muscular Agonism & Antagonism

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Abstract

Surface electromyography (SEMG) dynamic protocols of testing of the activity potentials of the myotatic unit of the elbow have been used to define the muscular relationships of agonism & antagonism. The values of the correlation coefficients of the different muscles, computed through the elbow ROM segments served to establish positive or negative relationships among the elbow muscles. Thus, the concept of muscular agonism & antagonism was verified and brought to objective light with the SEMG investigation. Such testing was conducted for the elbow joint ROM as well as all the other major joints.

Keywords

SEMG (surface electromyography), correlation coefficients, agonism (synergism), antagonism, elbow ROM, extension, flexion, pronation, supination, anconeus, biceps, brachialis, brachioradialis, triceps

Introduction

The expressions of muscular agonism (synergism) and antagonism have not been questioned throughout the modern era of medicine. We tend to use the words almost indiscriminately to define a functional relationship among various muscles or segments of motion, usually within the same myotatic unit, but sometimes among muscles subtending different joints. The concept has not quite been questioned, nor clearly focused on or defined. The closest anatomical definition may relate to the actual position of a given muscle on a bone & joint. We tend to describe muscles positioned on the opposite sides of a bone/ joint as “antagonists” and muscles positioned on the same side of a bone/ joint as “agonists or synergists”. There is no actual study available to demonstrate the functional relationship ascribed to those words. The concept may further imply that one muscle may move the joint in one direction, e.g. elbow flexion, while the other may be “inhibited” during such motion and the corollary may apply to the opposite motion, e.g. elbow extension.
The concept applies poorly to other segments of motion that are neither flexion nor extension, yet, in the case of the elbow, pronation & supination.

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The advent of the ability to test skeletal muscles with SEMG allowed for statistical applications of the objectively derived data of electrical amplitude values through the different segments of motion of any given joint by the subtending muscles. Thus, in the case of the elbow joint, one can test the primary elbow joint muscles, i.e. the anconeus, biceps, brachialis, brachioradialis & triceps through the segmental motions of elbow extension, flexion, pronation & supination.

The data of the amplitude potentials of any of these muscles through the elbow joint ROM could be compared to that of the other muscles in terms of statistics of correlation coefficients.

The comparisons result in correlation data which is either positive or negative, according to the tendency of any muscle to become more or less active through a given segment of motion, especially by comparison with its neighbors from the same myotatic unit. Such data could then be translated in terms of correlational relationships of muscular agonism (synergism) or antagonism. The positive correlation coefficients represent muscular synergism. Negative correlation coefficients represent muscular antagonism.

Thus, the old concept of agonism & antagonism, never tested could be verified with the new technology. In a number of cases, the old assumptions were found to hold, in a number of other cases, they did not. The correlation coefficients among the muscles tested through any major joint ROM have been calculated and published in a number of textbooks.[1,2]

The present article describes the actual modality of the testing which allows for the statistical results that, in turn, define the functional inter-muscular and inter-segmental motion relationships of agonism & antagonism.

Methods

An SEMG dynamic protocol of testing of the elbow muscles through the elbow joint ROM has been utilized for the purpose of defining the muscular correlation coefficients described in the present article. The protocol has been previously published.[3]

-Participants: a number of asymptomatic individuals underwent the elbow ROM testing with SEMG. The individuals were about equally divided between the two genders. All were adults ranging between 19-69 years of age. Five muscles were utilized for the testing: the anconeus (N=75), biceps (N=76), brachialis (N=71), brachioradialis (N=75) & triceps (N=76). The utilization was bilateral. All the participants were able to perform a full elbow joint ROM, with no joint or myofascial restrictions.[4]

The testing was performed at the effort level of minimal voluntary contraction.

-Equipment: the testing has been conducted on Myovision 3000 SEMG equipment, 8 channels of SEMG.[3]

The specifications of the equipment were as follows.[3]

Input Impedance:	1,000,000 MegOhms
Resolution:	10 Bit A/D
Safety:	5000 Volt optical Isolation
Power Supply:	UL Medical Transformer
Filtering:	25-5000 Hz Wideband
Range:	Scanning at 0.08 – 200 Microvolts
Calibration:	Lifetime through AutoCal

The testing was conducted after calibrating the equipment according to the manufacturer's instructions before each examination.
The SEMG electrodes were of the Ag/AgCl gel type. The electrode placements on the elbow muscles were done in the standardized positions described in the textbooks.[3,5]

-Procedure: the testing protocol was such that each segment of motion was measured through five repetitions of elbow segmental activity and rest, each motion being tested through 7 seconds of activity at the minimal effort of contraction (eccentric or concentric) and a 2 second period of 'return to resting state'.

The testing was done with the subjects in the standing position and the resting period was performed with the elbow/ upper limb in the neutral position, the arm hanging freely by the body. The positioning was according to the instructions given in standardized texts.[4,6]

All persons tested agreed with the examination and were informed about its purpose and lack of invasiveness. The participants were instructed beforehand how to proceed with the testing. No participant had any elbow joint restrictions, myofascial or neuromuscular symptoms or restrictions.

In summary, the data described and discussed below are a compilation of the statistics gathered from the testing of 373 muscles tested through 4 segments of elbow ROM, each segment measured through 5 repetitions of full motion. Thus, the data derive from a total of (373 x 4 x 5) =7460 measurements. The data consisted of activity & resting potentials calculated by the software in terms of microvolt RMS (μV RMS) SEMG values of amplitude domain.
The raw data obtained from the testing was utilized for the compilation of statistics for the purpose of establishing the correlation coefficients necessary for the understanding of the inter-muscular relationships.

The following statistics were compiled from the data:

a) Similar statistics compiled for each muscle tested in a number of participants, (N);

b) Average activity potential amplitude values (μV RMS) of each segmental motion for each muscle, mean value for the 5 repetitions of each motion, mean value for the number of muscles (N);

c) Standard deviation (S.D.) and lower & upper 95% confidence intervals (<95% & >95% C.I.) values for the average value of muscular segmental motion, for each muscle tested;

d) Statistics of correlation coefficients (C.C., r^2) among the five elbow joint muscles & segments of motion tested.

Results

The results are tabulated in the tables below.

Table 1. Activity potentials (µV RMS) data of 5 elbow joint muscles tested through four elbow ROM segments of motion with SEMG.

See Excel Table 1 at the end of the article

Table 1 shows the statistics of the activity potentials of elbow muscular activity in the four segmental motions tested.

The data show that the anconeus muscle is the most active of the group at the minimum effort of motion level. The ranking in terms of overall amplitude of activity is that of anconeus, biceps, brachioradialis, brachialis & triceps.

There is an obvious range of average segmental activity for each muscle tested. Of all values of the four muscles, pronation of the anconeus shoes the highest activity (43.6 µV RMS) amplitude and supination of the triceps shows the lowest amplitude (6.3 µV RMS). The average amplitude of electrical activity potentials for the 5 muscle group moving through the elbow joint ROM was 19.7 µV RMS. In general, the lower and upper 95% confidence intervals (C.I.) were 19% lower & higher than the average amplitude values for the group. The average activity/ rest ratio for the group as a whole was 12.4.

This represents the statistics of the ratio of the overall segmental activity of the elbow ROM for the 5 muscles above to the overall minimal resting potentials for the muscles tested. The average minimal resting potential for the group was 1.6 µV RMS, a well expected value for resting potentials for the skeletal muscles tested as a whole.[1,4,7]

Thus, the 5 elbow joint muscles tested show a 12 fold activity pattern as compared to minimal resting values through the elbow ROM. An examination of the probability (Prob. > F) value for each muscle tested showed a significant difference for the four segments of motion as a whole. The average Prob. > F value for the 5 muscles tested was 0.004, indicating a significant difference for each elbow joint muscle tested.

An examination of the inter-segmental variance for each muscle showed that there were some significant and some non-significant differences in the inter-segmental variance. A total of 9 inter-segmental non-significant variance were found and a total of 11 significant variance differences were found. Thus, some inter-segmental differences were significant in terms of the elbow ROM segments.

Table 2: Elbow segments of motion correlation coefficients among the 5 muscles tested with SEMG

See Excel Table 2 at the end of this article

Table 2 shows the positive and negative correlation coefficients calculated from the comparison muscle to muscle for the four segments of elbow ROM tested with SEMG for the 5 muscles.

It may be of note that all muscles except one showed a high level of correlation, i.e. > .75 (or -.75) with the exception of the biceps to the triceps at -.74 and brachioradialis to the triceps at -.58.[1]
Anconeus had strong negative correlations with the biceps, brachialis and brachioradialis and a strong positive correlation with the triceps. Biceps had strong positive correlations with brachialis and brachioradialis and strong negative correlations with anconeus. The correlation with the triceps was moderately strong and negative. Brachialis had strong positive correlations with biceps and brachioradialis and strong negative correlations with anconeus and triceps. Triceps had moderately strong negative correlations with biceps & brachioradialis and a strong negative correlation with brachialis. It had a strong positive correlation with anconeus.
The overall pattern of correlation coefficients corresponds generally with the anatomic location of each muscle. It is easy to envisage the anatomic "opposition" of biceps & brachialis versus the triceps. On the other hand, the anatomic correlation between the anconeus and brachioradialis does not quite correspond with the classic interpretations of agonism and antagonism. The correlation coefficient data are discussed in the discussion section in terms of correspondence with the functional terms of agonism (synergism) and antagonism.

Table 3: Average SEMG amplitude potentials (µV RMS) of the 5 muscles tested with SEMG through the elbow joint ROM segments
See Excel Table 3 at the end of this article

Table 3 shows the average values of the SEMG amplitude potentials of the 5 muscles tested through the elbow ROM. The extension segment has the total highest amplitude potentials, only slightly higher than the flexion segment.
The pronation segment requires the least effort of the muscles tested in terms of the overall minimal effort level of activity. It may be noted that while there is an almost 3 fold difference between the total electrical activity expended by the highest activity muscle, the anconeus and the lowest activity muscle, i.e. the triceps, the same pattern does not reflect in terms of the overall electrical activity expended for the different elbow joint segments of motion. The largest difference is between extension and pronation, however only 16% difference in amplitude potentials.

Table 4: Correlation coefficients of the elbow ROM segments of 5 muscles tested with SEMG
See Excel Table 4 at the end of this article
Table 4 shows the correlation coefficient among the four elbow joint segments of motion as derived from the testing of the anconeus, biceps, brachioradialis, brachialis and triceps muscles with the SEMG dynamic protocol. The data show no negative correlations coefficients (r^2). The highest positive correlation between two motions was found between extension & supination, followed closely by the relationships between flexion & supination and flexion & extension.
The relationship between flexion & pronation was very low, compatible with the definition of *stabilizer* relationship.[1]

Discussion

The data shown in tables 1-4 aim at re-defining the old concepts of muscular agonism (synergism) and antagonism. A review of pertinent literature finds the expressions of muscular agonism and antagonism as functional expressions without specific definitions.[8] The Gray's Anatomy textbook does not even contain the words in its index.[9]

The Stedman's Medical Dictionary defines agonist as "*denoting a muscle in a state of contraction, with reference to its opposing muscle, or antagonist."* The definition of antagonist is "*that which opposes or resists the action of another; denoting certain muscles…. that tend to neutralize or impede the action or effect of other muscles, etc.*

The definition of associated antagonist is that of "*one of two muscle or groups of muscles which pull in nearly opposite directions, but which, when acting together, move the part in a path between their diverging lines of action".*[10]

While the definitions above are enticing, they do not necessarily reflect objective functional relationships. Just noticing the anatomic position of a given muscle does not reflect necessarily on its activity through the range of motion (ROM) of the primary joint of action. A study of the data in table I show that all the five elbow joint muscles are active through the four classic segments of elbow ROM.

Thus, the old idea that a muscle such as the triceps is primarily a muscle of extension of the elbow can be brought into question since the triceps is more active in elbow pronation than in extension.

The same applies to the anconeus muscle, thus showing that this is not an exception to a rule.

With regards to the brachialis, the muscle is most active in supination, followed by extension and then by flexion. The brachioradialis is more active in flexion than in extension. The biceps is most active in supination followed by extension and then by flexion.

The dictionary definition, reflective of old thought, considers agonism & antagonism only within the perspective of two opposing motions. Yet, with the exception of the knee, all other major joints have a larger number of classic segments of motion.[1,2,7]

Until the advent of SEMG dynamic studies and protocols, it was rather difficult to identify and measure the activity pattern of discrete muscles within a myotatic unit and within a given joint ROM. This technique allows for the simultaneous bilateral measurement of the electrical potentials of amplitude values of different muscles through a given set of segments of joint motions. Thus, one can identify the pattern of electrical amplitude of potentials for any segment of joint motion tested for a group of muscles such as a myotatic unit.

The 5 muscles tested with SEMG described above represent the elbow myotatic unit in terms of primary insertion & vector of action as well as direct inter-connecting fascia.

Table III presents the data in terms of both the average amplitude of activity potentials (µV RMS) for each muscle tested as well as for each elbow joint segment of motion. It is noticeable that the ranking of the muscles through the elbow joint ROM is (from high to low) anconeus, biceps, brachioradialis, brachialis and triceps when the motions are performed at the minimal effort level of contraction in the standing position.

The ranking pattern from high to low in terms of the segments of motion is that of extension, flexion, supination and pronation. These data have relevance both in terms of ergonomic planning and in terms of muscular rehabilitation or optimization for a variety of activities.
It is relevant to note that there is a difference of 63% in the activity amplitude pattern between the highest and lowest ranking muscle, whereas there is only a difference of 16% in terms of the highest and lowest segments of motion ranking. Thus, a clinician involved in elbow joint muscles rehabilitation, may consider appropriately those findings in terms of neuromuscular rehabilitation.[11]

Table 4 represents the correlation coefficients (r^2) calculated from the segmental data of the 5 muscles tested through the elbow joint ROM with SEMG.

If the respected old time definition of antagonism between two motions were to hold, then the elbow motions of flexion & extension should have shown a negative correlation, corresponding with the concept of antagonism. However, the correlation showed $r^2 = 0.83$, a high positive correlation. Therefore, the reality of having 5 muscles directing joint activity through the two motions supercedes the theoretical concept of antagonism, based on the anatomical observations of muscular positions on opposite sides of a given bone and acting "primarily" in concentric contraction. As the data in table 1 and 3 show, the 5 muscles act through the four segments of elbow joint motion, either in concentric or in eccentric contraction.
Thus, the old concept can no longer be considered valid in the face of the reality of electrical activity. While the biceps is contracting concentrically through flexion (avg 36.9 µV RMS), the triceps is contracting eccentrically simultaneously (avg 9.6 µV RMS). By the same token while the biceps is contracting eccentrically through extension (avg 27.1 µV RMS), the triceps is contracting concentrically simultaneously (avg 14.4 µV RMS).
It is noticeable that in both motions the biceps has higher activity potentials than the triceps. The same considerations would apply for any given muscle and its partners in the myotatic unit through the motions of pronation and supination.
These two motions show a moderately low correlation coefficient ($r^2 = .4$), however, not a negative or antagonistic correlation.
What does the *stabilizing* relationship between flexion & pronation signify? An $r^2 = 0.05$ is defined as a stabilizing relationship of mutual support through any motion with and against gravity, thus only a myofascial relationship between two muscles or two segments of the same joint ROM.[1]

The four tables from the results section aim to redefine the concepts of muscular agonism (synergism) and antagonism. The data show clearly that the muscles of a primary myotatic unit are active through any primary joint segment of ROM, whether they act in a concentric or eccentric contraction. The data rebuke the old concept that the "agonist is active" and the "antagonist is inhibited" through the concentric contraction of the agonist. Those old concepts do not correspond to the reality shown by the SEMG dynamic studies and, in fact, have never been demonstrated by any in vivo studies of any kind.

The data show not only the relationships among the 5 muscles of the elbow joint myotatic unit but also among the four segments of motion tested.
Table 2 shows six antagonist relationships among the muscles tested and five agonists relationships among the same muscles. Thus, the elbow joint ROM has an imbalance among the agonists & antagonists relationships among the muscles tested.
Table 4 shows that there are five agonist relationships and one stabilizer relationship among the four elbow segments of motion, when the five muscles representing the primary myotatic unit of the elbow joint are tested with SEMG.
Thus, the concept that flexion & extension or pronation & supination should be antagonistic relationships does not hold in terms of the reality of 5 muscles acting simultaneously with concentric & eccentric motions through the given elbow joint ROM.
What are the potentials applications of the new knowledge from the data described in this article?
The answer is two fold. Within the rehabilitation realm, one can utilize the data as a comparison to actual clinical/ SEMG presentations in the neuromuscular dysfunction field and investigation. Once the clinician has compared the data on muscles affected by pathology or dysfunction to those from asymptomatic muscles, such as described above, one is enabled to institute a more specific treatment plan. Thus, the plan should include amplitude potentials through the elbow range of motion within 20% of those found in table 1 and aim to bring back the dysfunctional muscles activities to within those amplitude potential limits for any given muscle and elbow segment of motion.

By the same token, one can assess the initial correlation coefficients of the dysfunctional muscles and compare the r^2 values to those expected for asymptomatic muscles through the elbow ROM. The treatment plan should include the aim of normalizing the correlation coefficients to become similar to those described in tables 2 & 4.
Within the ergonomic field, the specialist will aim to construct machinery or work environments that conform to the application of the least effort through motions performed by the above muscles. In a practical vein, one would want to build machinery that would utilize the biceps, brachialis and brachioradialis in pronation rather than in flexion or extension. Within the ergonomic/ sports arena, one would want to involve the muscles in such a way that they react with the least amount of electrical effort, paralleled by the least amplitude potentials.
Thus, the athletic trainer may utilize the data from tables 1 & 3 as the data bases for comparisons with the muscular effort performed before training by the participants and aim to reduce that effort as far as possible to within the limits shown in tables I & III.
The same argument applies within the ergonomic or athletic fields in terms of the correlation coefficients noted on tables 2 & 4. One can compare the pre-training data of correlation coefficients to the data shown on those tables and aim at improving the overall correlational values either among muscles or among the elbow segments of motion tested to conform to those shown in the tables and / or improve on them.

Conclusions

In summary, the old concept of muscular and joint motion relationships of agonism & antagonism has been revisited in new light. SEMG dynamic protocols have been utilized to demonstrate the actual electrical amplitude potentials derived from the movements & activity of each muscle through each classic elbow joint ROM. The results demonstrated a number of positive & negative correlations (r^2) among the muscles tested through the four segments of motion. The results were easily interpreted in terms of agonism & antagonism among the 5 muscles tested.

When the data were calculated in terms of the correlation coefficients (r^2) among the four segments of motion, it resulted in only positive correlations, mainly of agonist type, with one stabilizing relationship.

Thus, the old concept of muscular or joint motion agonism & antagonism has been modernized and objectivized with the technique of SEMG dynamic testing of the muscles pertaining to a primary myotatic unit, technique which allows the actual measurement of the electric potentials expended by any given muscle through any given joint segment of ROM.

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