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OBSERVATION OF CONTRACTION ON HUMAN SKELETAL MUSCLES IN SITU

— Fast and Slow Contracting Muscle —

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Abstract

A simple device to pick up contraction force of a human skeletal muscle in situ as the muscle is electrically stimulated at the same point has been developed and used on eleven normal subjects. Some abnormal subjects were also studied.

Latency of contraction with stimulation at the motor point was measured in deltoid, biceps brachii, triceps brachii, extensor digitorum communis, adductor pollicis, quadriceps femoris, soleus, gastrocnemius and tibialis anticus. The muscles in the upper extremity show uniform latencies and these are shorter than those of the lower extremity muscles.

Critical fusion frequency of stimulation necessary to produce complete tetanus was measured in the same muscles mentioned above. Deltoid, biceps brachii, soleus and tibialis anticus muscles are classified as slow contraction muscles. Triceps brachii, extensor digitorum communis, adductor pollicis, quadriceps femoris and gastrocnemius are fast muscles.

INTRODUCTION

There have been few quantitative observations on the contraction of the human skeletal muscles, although electrical stimulations of muscles and the nerves have been used routinely as one of the most important methods for both diagnosis and therapy of neuromuscular disorders. One of the major difficulties in the quantitative observation is methodology, especially when one wants to record contraction curves.

In most of the past studies[1,2] contraction of thumb adductors have been recorded by means of a force transducer which is attached rigidly to the thumb. Others[3] recorded contractions of the calf muscles with the same principle. This method has limited use on only a few limb muscles.

A direct application of a piezo-electric transducer over human muscles in situ to record contraction curves was tried with electrical stimulation of the nerve or the muscle remote from the transducer[4]. Delmas-Marsalet[5] used a pneumatic tambour with a stimulating electrode on it to pick up contractile force as the muscle was stimulated. Little attempt was made to prevent distortion of the curve by intertias or frequency responses of the instruments.

The present study aims to develop a practical device to record contractions of human muscles in situ with less distortion of inertial lag or frequency response defects of earlier devices. The study was also planned to measure the latency of contraction of individual muscles. A third aspect of the study is an effort to classify skeletal muscle in two functional groups, that is, fast and slow contracting. There has been a classical differentiation of skeletal muscle according to its red or white color. They also have been distinguished as slow or fast contracting muscles. Recent electromyographical[6] and histo-chemical[7] studies have further amplified this early crude distinction.

METHOD

A piezo-electric crystal element from a convential phonograph cartridge was used to convert muscle force into an electrical signal. A metal disc of 8 mm in diameter was attached to a steel damper springboard. The damper was then connected to the crystal by means of a thin metal rod. The metal disc served two purpose; one was to transmit the force from the muscles to the crystal and the other was as a stimulating electrode. The unit was mounted on a wood handle (Fig. 1). A small amount of electrode jelly was placed on the disc when it was applied on the motor point of a muscle.

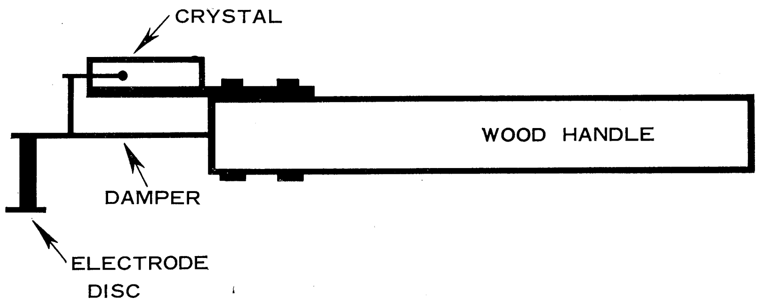


Fig. 1. Transducer-stimulating electrode assembly.

Amplifier: A Tektronix type 122 preamplifier was used to condition the output of the crystal. The frequency responses of the preamplifier was set at 0.2 Hz to 10 k Hz. Overall frequency responses of the crystal and the amplifier were 2.5 Hz to 1 k Hz.

The output of the preamplifier was displayed on Tektronix type 502 oscilloscope and was also fed to a CAT 400 B computer. Osccilloscope display was pictured by a Grass model 4 C camera. The computed averaged responses were recorded by a Varian G 1000 chart recorder.

Stimulator: A Grass model S 8 stimulator with model SIU 5 isolation unit was used. The cathode was connected to the stimulating electrode and the anode was to a large indifferent electrode (15 cm × 15 cm) placed on a subject's back. Intensity was supra-maximal and ranged from 50 to 100 V. The sync output of the stimulator triggered both oscilloscope and the CAT. Eleven healthy human subjects (7 males and 4 females) of ages 17 to 50 years were tested.

The muscles examined were the deltoid, biceps brachii, triceps brachii, extensor digitorum communis and adductor pollicis in the upper extremity; and quadriceps femoris, soleus, gastrocnemius, and tibialis anticus in the lower extremity.

1) Latency study: Electrical stimulation with 0.1 msec pulse duration at a rate of 1 per second was used. The time between the stimulation and the very beginning of the muscle contraction was defined as the latency of contraction in this study. Ten responses for each muscle were averaged.

Tests were done on both left and right sides in eleven subjects. Studies on quadriceps muscles were not done in three female subjects.

2) Tetanic contraction study: The muscles of only one side of the body were studied in eight subjects (6 males and 2 females) in this study. The quadriceps muscles in one female subject was not tested.

A train of high frequency stimuli (each stimulus with 0.1 msec pulse width) which lasted approximately 0.5 seconds was used. The frequencies were 30, 40, 50, 60, 70, 80, 90, 100, 120, 140 and 160 per second. This train of high frequency stimuli was applied on the motor point every two seconds. Ten reponses were accumulated by the CAT with an analysis sweep time of 0.5 second. Ripples in the contraction curves were enhanced by this CAT accumulation technique. This was used to facilitate determining complete tetanic contraction.

RESULTS

1) Latency of contraction

The latency of contraction determined under relatively isometric conditions and again under relatively isotonic conditions in the same muscles revealed no difference (see Fig. 2, a and b.) However, the shape of the contraction curve was noted to differ significantly under these two conditions.

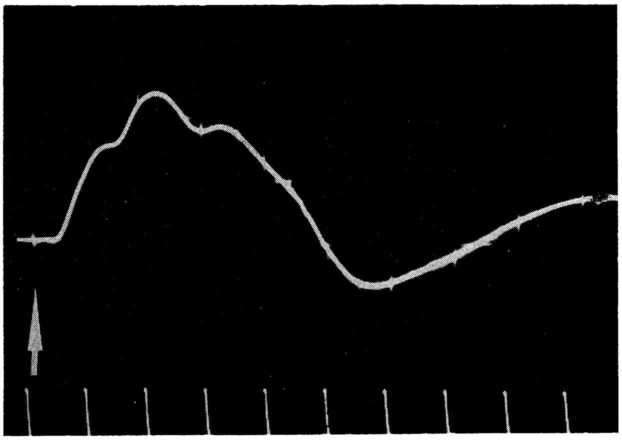
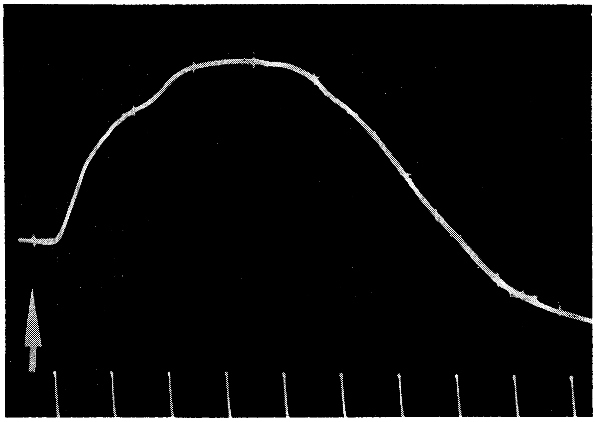


Fig. 2 a. Isometric contraction curve of normal biceps brachii muscle.
Time mark: 10 msec.



Fib. 2 b. Isotonic contraction curve of same biceps.
Time mark: 10 msec.

Table 1 shows a summary of the results in the eleven subjects. These results were obtained while the subjects were relaxed and the limbs in a neutral position.

The variation of latencise among the upper extremity muscles was found to be negligible but the latencies of the lower extremity muscle were significantly varied and generally they were larger than those of the upper extremity muscles.

TABLE 1. Latency of contractlon

	MEAN ±Standard Error (msec)	S. D.
DELTOID	3.7±0.05	0.24
BICEPS BRACHII	3.7±0.05	0.24
TRICEPS BRACHII	3.7±0.08	0.38
EXTENSOR DIGITORUM COMMUNIS	3.6±0.06	0.27
ADDUCTOR POLLICIS	3.7±0.06	0.25
QUADRICEPS FEMORIS	4.3±0.08	0.30
SOLEUS	5.7±0.17	0.78
GASTROCNEMIUS	5.0±0.11	0.50
TIBIALIS ANTICUS	4.5±0.07	0.31

22 muscles (bilateral) of 11 subjects except quadriceps femoris which is from 16 muscles of 8 subjects.

2) Tetanic contraction

When the frequency of the stimulation is raised the muscular contraction becomes smooth. This is observed as a smooth line without ripples on the contraction curve displayed by the CAT. The lowest frequency to produce complete tetanic contraction is the so called critical fusion rate. The critical fusion rate measured under relatively isometric conditions and under relatively isotonic conditions in the same muscle showed no difference, as in the latency of contraction. The rate for each individual muscle is indicated in Table 2. Individual results are shown as well as averages since the number of samples are small.

The muscles which had a critical fusion rate of 100 per second (average) or higher were triceps brachii, extensor digitorum communis, adductor pollicis, quadriceps femoris and gastrocnemius. Those which had a fusion rate lower than 100 per second were deltoid, biceps brachii, soleus and tibialis anticus.

DISCUSSION

1) Latency of contraction

The latency of muscular contraction after an electric stimulation of a muscle at the motor point (8) probably includes,

TABLE 2. Critical fusion rate (per second)

	DELTOID	BICEPS BRACHII	TRICEPS BRACHII	EXTENSOR DIGITORUM COMMUNIS	ADDUCTOR POLLICIS	QUADRICEPS FEMORIS	SOLEUS	GASTROCNEMIUS	TIBIALIS ANTICUS
A.K. 36, M	80	70	100	100	100	120	90	140	70
P.U. 32, M	70	50	90	90	100	* ** 100(70)	70	120	60
H.N. 34, F	80	60	80	80	90	90	50	100	60
E.L. 35, F	60	50	90	120	120	—	60	80	60
A.G. 33, M	70	60	90	140	120	120	90	120	60
J.S. 18, M	80	60	140	120	120	140	60	140	60
M.K. 28, M	90	60	120	140	100	90	90	120	80
C.L. 17, M	90	60	90	140	140	100	80	120	70
MEAN	78	59	100	116	111	109	74	118	65
S.D.	10	6	19	22	15	17	15	19	7

* LEFT ** RIGHT

a. transmission time at the neuro-muscular junction,
b. time to set up some basic reaction of the contractile material in the muscle fiber and
c. mechanical delay between the muscle and transducer.

There have been very few studies carried out on the latencies in human muscle contraction. In those studies, the latent periods measured are very much longer than those measured in isolated animal muscles. The animal muscles reportedly showed latent periods of 1 to 2 msec between the electromyographical response and beginning of contraction. Bothelo and Chandler (1) stimulated the ulnar nerve at the wrist and recorded contraction of the adductor pollicis muscle by means of a transducer attached to the thumb. The latent period they measured in seven subjects averaged 18.3 msec. One of the disadvantages of the method in which the transducer is attached to a finger or limb is mechanical delay at the joint and at the junction of the muscle and the transducer. The present system virtually elimates these factors of mechanical delay as the transducer is applied over the muscle and presses the muscle firmly against bony core structures. As the muscle contracts, its diameter increases. The increasing muscle diameter exerts a force against the transducer. This diminishes the inertial lag defect of previous studies.

The latencies of the muscles in the upper extremity were almost uniform whereas those of the lower extremity muscles varied considerably and were always larger than the former. This could be attributed to the size of the limbs and muscles. Generally, the muscles in the lower extremity are larger than those in the upper extremity. Thus there is a bulkier mass of soft tissue between the transducer and the bony core; thus a larger mechanical delay from muscle to transducer might result. In pathological conditions of muscles, the latency of contraction becomes larger. One example is shown in Fig. 3. This is a 20 year old man who showed weakness of the right biceps brachii muscle after a closed injury to the arm. The EMG showed a few fibrillations at rest and some normal motor units and polyphasic potentials during voluntary contraction. The latency of contraction of the biceps was 12 msec which is markedly longer than the normal average.

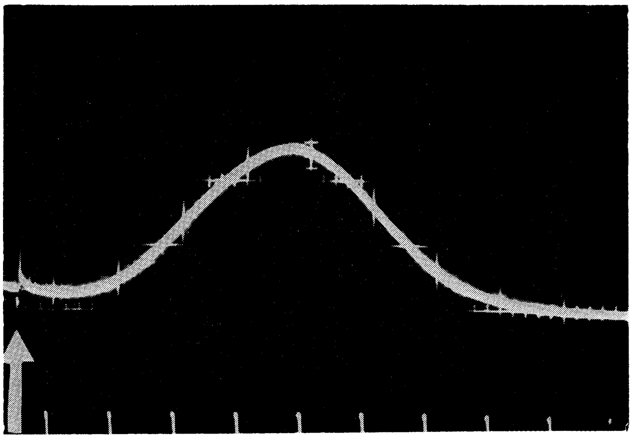


Fig. 3. Contraction curve of partially denervated biceps brachii muscle. Time mark: 10 msec.

2) Tetanic contraction

The classical differentiation between red and white skeletal muscle has been amplified by histochemical studies[7] as well as electromyographical studies[6]. More recently, slow fibers have been divided into two sub-groups both physiologically and histochemically[9,10].

The motor unit which performs phasic fast contraction represents the classical "white" muscle fibers and is designated as the kinetic motor unit by Tokizane and Shimazu[6]. On the other hand, the tonic motor units perform slow sustained contractions and they consist exclusively of red muscle fibers[7].

In the human, in the majority of limb muscles these red and white muscle fibers are intimately mixed[11]. The proportion of tonic and kinetic motor units in a muscle may vary in accordance with the function of the muscle[12,13] Human soleus muscle performs relatively constant sustained contraction, whereas the gastrocnemius performs fast phasic contraction[14]. Electromyographically, Kawakami found that the soleus has relatively more tonic units and the gastrocnemius has more kinetic units in random sampling[12]. Histochemically[16], the soleus is predominantly composed of red fibers. Yamaya[13] electromyographically obtained a ratio between tonic and kinetic units (T/K) in human subjects. The ratio T/K in biceps brachii is 1.24, in extensor digitorum communis is 0.74 and in deltoid is 1.84.

The critical fusion rate of stimulation necessary to produce complete tetanus is higher for fast muscles with a relatively brief contraction time (the time between onset of contraction and peak of contraction) and is lower for slow muscles with longer contraction time[16]. Therefore, there are at least two ways to find out whether a given muscle is fast contracting and relatively rich in kinetic units or slow contracting and rich in tonic units. One is to record the contraction curve to get the contraction time and the other is to measure the fusion rate by stimulating the muscle. The former was done by Liberson[4] for a purpose different from that of the present study. However, it is difficult in an "in situ" condition to obtain an accurate contraction curve constantly since the curve varies its peak with isometric and isotonic contractions and practically no true isometric or isotonic conditions exist in situ. In the present study, the critical fusion rate was used. The results indicate that the triceps brachii, extensor digitorum communis, adductor pollicis, quadriceps femoris and gastrocnemius muscles are fast muscles and the deltoid, biceps brachii, soleus and tibialis anticus muscles are slow muscles. These results agree with the electromyographic studies of Kawakami[12] and Yamaya[13] mentioned above. The muscles with a critical fusion rate of less than 100 correspond to the muscels with relatively more tonic motor units while those greater than 100 correspond to the muscles with relatively more kinetic units.

A marked difference is noted between the biceps and triceps muscles of the arm. The biceps is found to be slower, probably with predominantly tonic motor units while the triceps would seem to be predominantly of kinetic type motor unit. However, Edström et al[17] showed histochemically in normal human muscles that the biceps was the whitest muscle among the muscles tested (vastus lateralis, tibialis anticus, soleus and gastrocnemius). One may speculate from the functional view point that the difference between the biceps and the triceps seen in the present study stems from differences in use of those muscles. The biceps is a slow heavy weight lifting muscle while the triceps is employed in faster and more rapid movements, such as throwing and hammering.

As has been said, the critical fusion rate of the muscles correlates well with the classification of the fast and slow contracting muscles made by both electromyographical and histological studies. However, it seems there is no correlation between the latency of contraction and the fast or slow character of the contracting muscle. All the muscles in the upper extremity show uniform latency of contraction regardless of whether they are classified as fast or slow. In the lower extremity, the fast gastrocnemius muscle and the slow soleus muscle show almost the same latency of contraction.

The critical fusion rate may change in pathological conditions of the muscle. One example is indicated in Table 2. Subject P. U. showed no subjective or objective weakness nor atrophy of the right quadriceps femoris but a definitely lower critical fusion rate than the left. He had a tibial tubercle transplant on the right 14 years earlier. After the surgery the leg was placed in a cast for six weeks and a moderate disuse atrophy was seen after the cast was removed. It took several years before the atrophy disappeared completely. The latency of contraction showed no significant difference. It was 4.7 msec on the right and 4.1 msec on the left.

The separation of skeletal muscles into fast and slow groups may be of some benefit in attempting to select a muscle source for artificial blood pumping devices. It would seem likely that a slow muscle would tolerate better the sustained action required of such devices. The fast quadriceps has been noted to fatigue and disintegrate when subjected to such use, as reported by Kusserow[18].

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