CALCULATING ANATOMICAL STRENGTH CURVES

Stanley PLAGENHOEF

Bennett Ergonomic Labs, Inc.
12305 62nd Street North, Suite B
Largo, Florida 33543

The anatomical strength curves for every joint in the human body have been calculated. This makes it possible to compare the relative strengths of muscle groups, both within a joint and between one joint and another. One can compare the flexor strength to the extensors of a selected joint, or compare knee extensor strength to shoulder flexion strength, or any combination desired. The percent contribution of each muscle, in a group having the same function, is given throughout the range of motion. This makes it possible to design exercise programs that use all the muscles of the body, or to develop a specific program for rehabilitation.

OBTAINING THE STRENGTH CURVES

There are several factors that must be determined to arrive at the strength curves for every muscle group.

1. The muscle leverage for each individual muscle throughout its range of motion.
2. The maximum cross sectional area of each individual muscle. Whether the muscle is striated or penniform must be considered.
3. The portion of the muscle that is being used, based on the leverage measurements. (The lower and upper portions of the Gluteus Maximus, or the forward or backward fibers of the Adductor Magnus can have varied functions.)
4. The angle difference between the muscle line of pull and the line of motion of the body part being moved.
5. The angle difference between the muscle line of pull and the muscle fiber direction for all penniform muscles.
6. The fiber length relative to the total length from bone to bone. Some muscles have long tendons and short fibers so they reach their end point of contraction before the limits of the range of motion of the skeleton is reached.
7. The variation in strength depending on the length of the muscle. The so called Length-Tension curve.

STEP BY STEP PROCEDURE FOR OBTAINING THE STRENGTH CURVE FOR HIP FLEXION

The group of muscles that are hip flexors are used to illustrate the procedure for obtaining strength curves. The muscle leverage was obtained for each muscle through a range of -40° to 120°. (Figure 1). Eleven muscles are involved with some of them contributing through part of the range, such as the Adductor Longus (Figure 2), some running out of contraction force due to a short fiber length relative to the total length (Tensor Fasciae Latae 36%), and some having a line of pull direction different than the line of motion, (all Adductors).

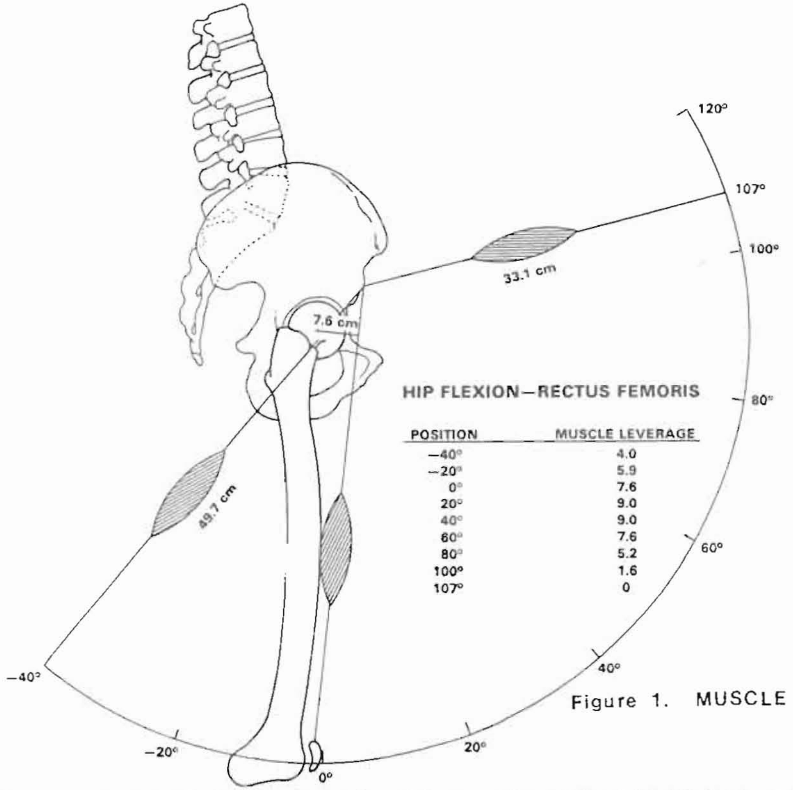


Figure 1. MUSCLE LEVERAGE

The cross sectional area of each muscle was calculated using a planimeter. The maximum cross section was measured from A Cross Section Anatomy by Eycleshymer and Schoemaker, (1938) and from a follow up book by Carter et al (1977) that revised their book correlating original diagrams with CT scanning and ultrasound.

The steps taken to get the relative strength of the group of muscles based on torque are:

1. Obtain the leverage of each muscle.
2. Correct the leverage for an angle of pull out of the plane of motion of the whole muscle.
3. Correct the leverage for an angle of pull out of the plane of motion for penniform muscles.
4. Obtain the cross sectional area of each muscle.
5. Correct the cross sectional area if the muscle fibers are not perpendicular to the cross section.
6. Correct the cross sectional area if the muscle is penniform and a single cross section does not cover all fibers.
7. Determine the portion of the muscle used from the leverage measurements.
8. Determine if a muscle fiber has contracted to 50% of its length where it loses its ability to apply force. (Table 1).
9. Multiply the corrected muscle leverage times the corrected cross section of each muscle and add these numbers for all muscles at one position in the range of motion. When this is done for every selected position throughout a range of motion, a graph can be drawn to obtain the strength curve. (Figure 3).

10. Determine the percent contribution of each muscle by dividing the leverage times cross section of each muscle by the leverage times cross section of the total group. (Table 2).

MUSCLE CONTRACTION LENGTH

When the fibers of a muscle equal 50% of the total length of a muscle, bone to bone, the muscle can contract to only 75% of its length before loosing its contractile strength. If the fibers were 90% of the total length, the muscle could shorten to 55% of its length. (Table 2). Steindler (1955) states that a muscle looses 80% of its strength at the terminal contraction point, and defines conditions regarding muscle length as:

1. Length of extreme stretching.
2. Length as restricted by the antagonist muscles.
3. Length of "normal" non-innervated muscle.
4. Length of maximum contraction.

It was found that almost all force was lost by a muscle when the fibers contracted 50% of their length, with the total muscle length calculated from the fully stretched position to the fully contracted position. This was found to be true when the fibers were only 50% of the stretched muscle length (gastrocnemius), or when two joint muscles had a very large range of motion to contend with as the hamstrings. Performing a prone leg curl,

HIP FLEXION—ADDUCTOR LONGUS

POSITION	MUSCLE LEVERAGE
−40°	7.3
−20°	8.1
0°	7.7
20°	6.2
40°	3.2
50° Change From Flexion To Extension	
60°	2.3
80°	6.0
100°	7.5
120°	7.7

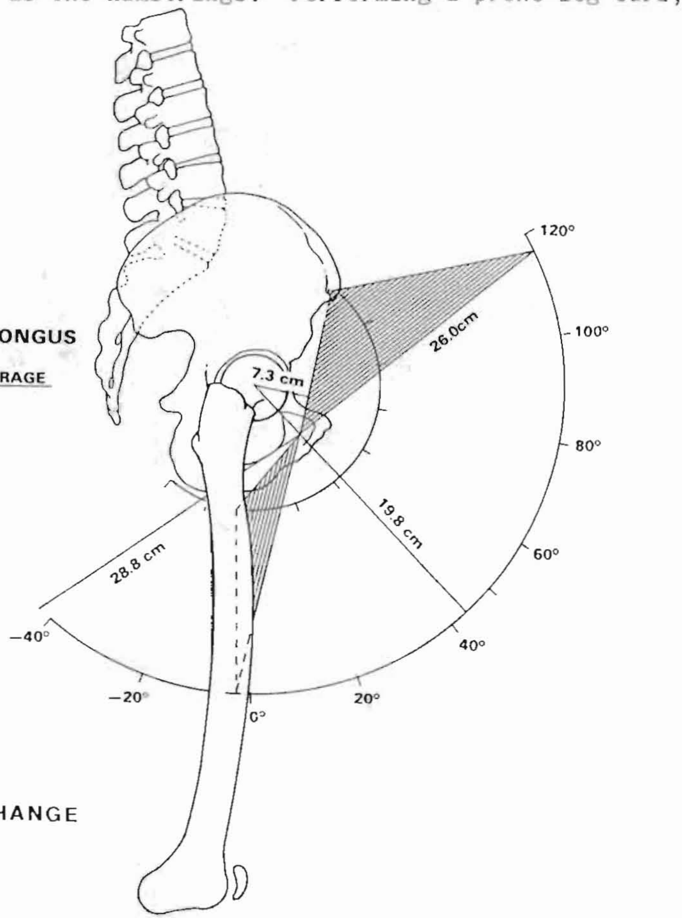


Figure 2. FUNCTION CHANGE

the gastrocnemius becomes flaccid at the end of the motion for most people if the foot is extended. Also, with the thigh in line with the trunk and the knee bent to full flexion, the hamstrings loose strength rapidly toward the end of the motion.

Following the steps outlined, it was found that the Psoas and Illiacus contributed throughout the motion, but to a greater extent as the flexion increased. The Rectus Femorus and the Adductors contributed the most at the beginning of the motion and reduced to zero by the end of the motion. The Sartorius and Tensor Fasciae Latae contributed slightly through most of the range. (Table 2).

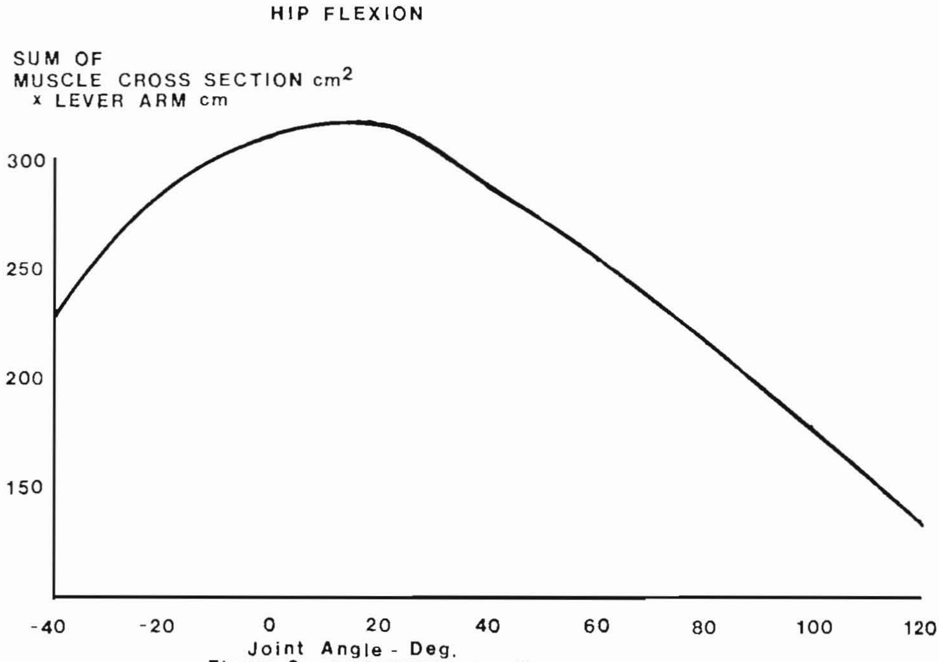


Figure 3 - STRENGTH CURVE

TABLE 1

Muscle fiber length to total length	Muscle contraction length relative to stretched length
50%	75%
60	70
70	65
80	60
90	55

The strength curve peaks at 20° and then falls off rapidly. Hip flexion was chosen as an example because the muscle contribution varies considerably throughout the range. Exercises can be prescribed by using the magnitude of the numbers as well as the percent contribution of each muscle throughout the range of motion.

TABLE 2
PERCENT CONTRIBUTION OF HIP FLEXORS

Hip angle	Rec.Fem.	Psoas	Illiacus	Add.	Sart.	T.F.L.
-40	16%	17%	8%	57%	1%	1%
-20	19	16	9	47	5	5
0	22	17	10	37	7	7
20	25	18	10	27	9	9
40	28	20	12	13	14	13
60	27	23	17	0	17	17
80	19	28	20	0	15	18
100	8	44	32	0	16	0
120	0	59	31	0	10	0

Combining the percent contribution with the strength curve gives you good information for determining exercise programs. The hip joint does not move backward to -40° very easily, but in this position the Adductors are the main contributors. The strength curve shows that from a straight body position through the first 40° of motion, the amount of weight that could be used is about twice as much as can be handled at the end of the motion. This is because all the muscles are involved while the Iliopsoas does 90% of the work at the end. Therefore, the appropriately light weight, with emphasis on the end of the motion, is the best exercise for the Iliopsoas.

LENGTH-TENSION CURVE

The strength of a muscle relative to its length is called the Length-Tension curve. Harrison Clarke (1966) presented a series of strength tests for muscle groups using a dynamometer that generally concluded that the greater the stretch on a muscle the stronger the force, and that strength became progressively less as the muscle contracted. The results

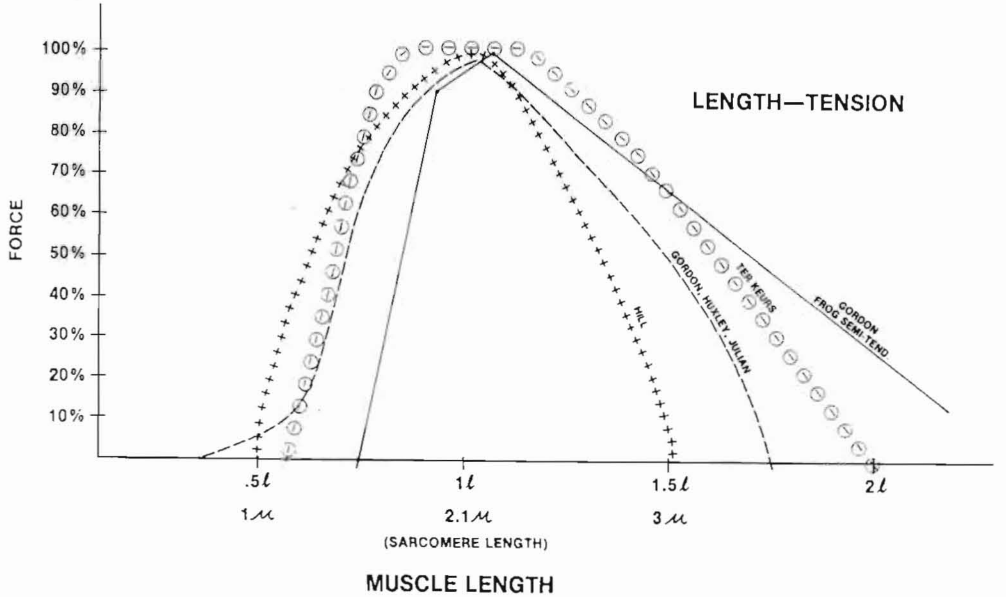
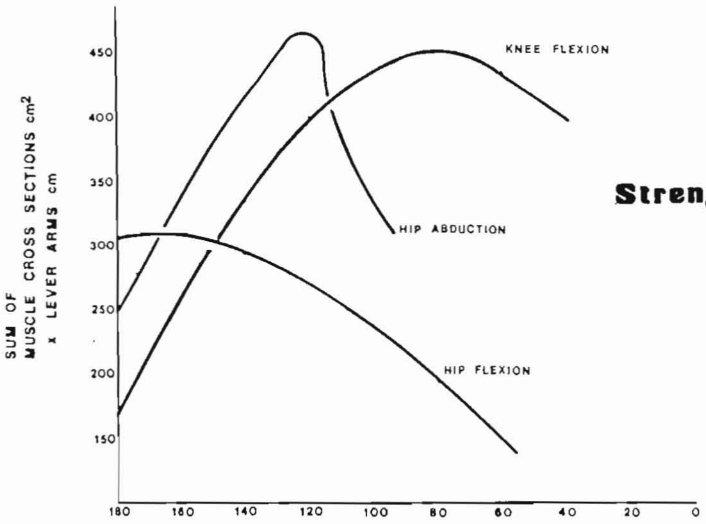
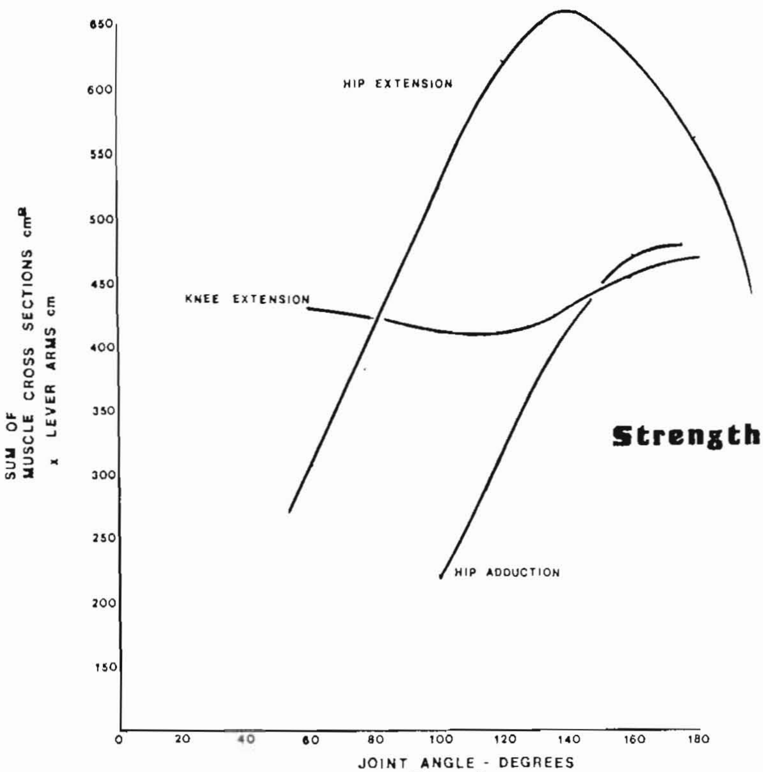


Figure 4 - SINGLE FIBER TETANIC TENSION



Strength Curves

Figure 5



Strength Curves

Figure 6

include all the muscles that cross a given joint with no relationship to a single muscle function. The A.V. Hill (1970) experiments with a frog gastrocnemius has been cited for proof that a muscle does not have the same force throughout its range of motion. Many researchers have done similar experiments tetanizing a single muscle fiber, but Gordon, Huxley, and Julian (1964) seem to be the most quoted. The force curves obtained are shown in Figure 4. If the passive stretch of a fiber, when it is elongated, is added to these curves, the force level would remain high at the end of its range. This is called force enhancement due to stretching. This would then produce the conclusion that a muscle gets progressively weaker as it shortens. This conclusion was then explained by the amount of overlap of the thick and thin filaments as a sarcomere shortens.

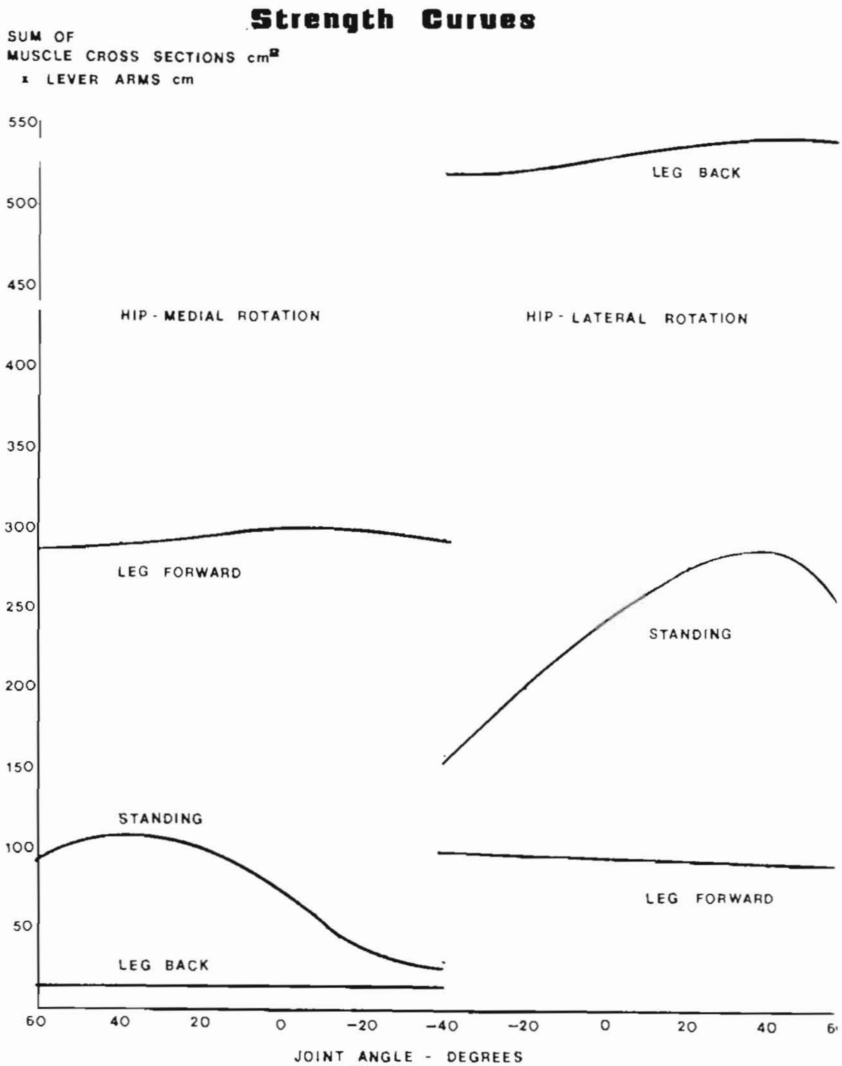


Figure 7

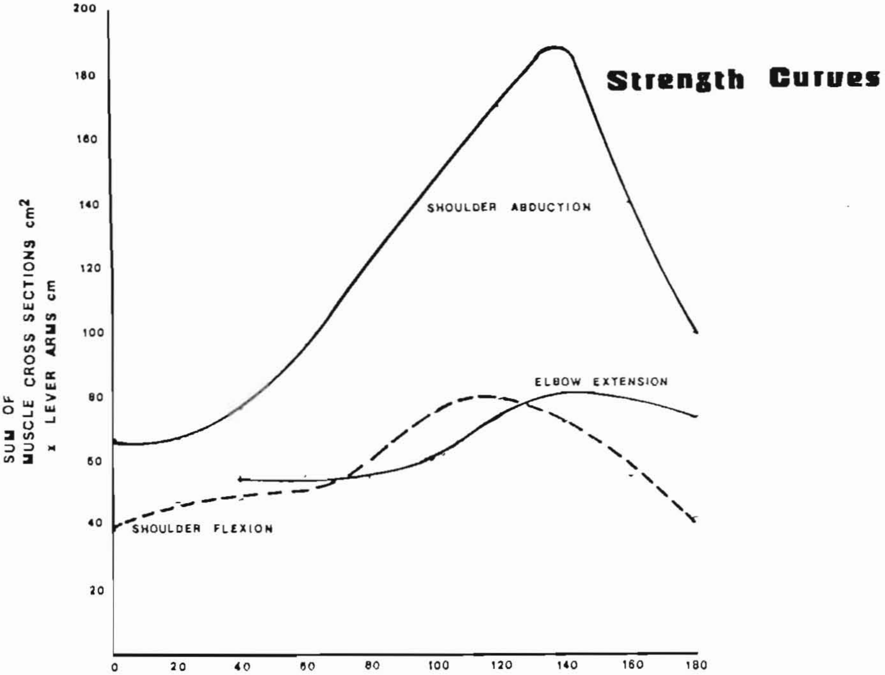


Figure 8

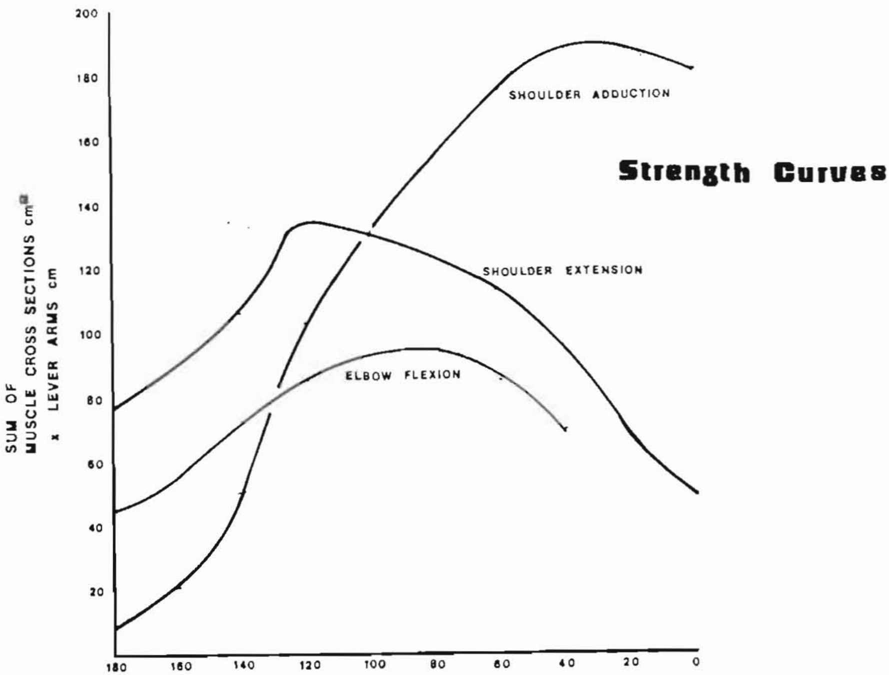


Figure 9

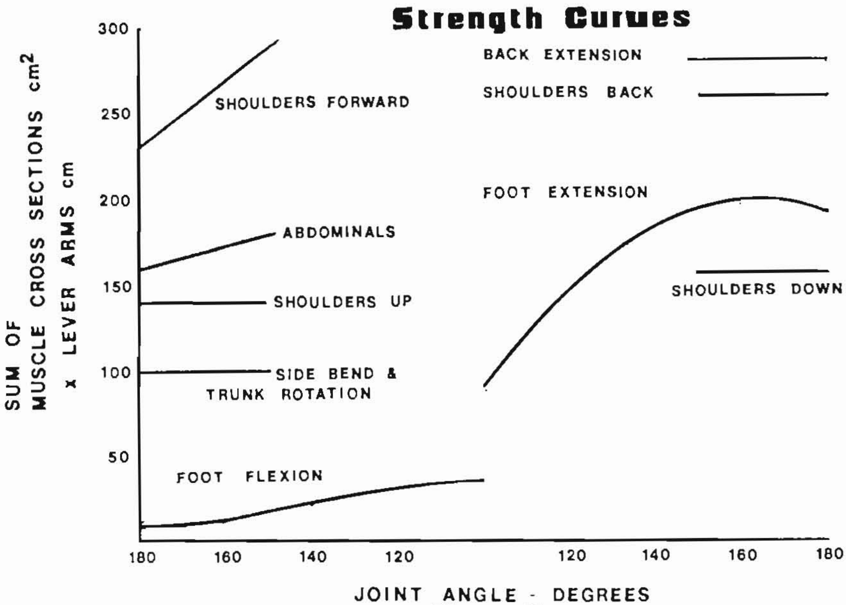


Figure 10

If force of contraction does change due to muscle length in man, it is necessary to include this information to obtain the strength curves. With the knowledge of the anatomical strength curves, without correcting for muscle length, it was necessary to find out how close to these curves man could come when tested properly. Because there are so many muscles involved across one joint, it is difficult to even find a joint to test. Another very large problem is to find a joint that can be tested where the adjoining body segment can be stabilized equally throughout the whole range of motion of the moving part. A segment can be stabilized by a solid table (the counterforce) during the start of a motion, and change to the muscles of the adjoining segment during the end of the motion. The leg extension and leg curl (lying prone) are examples of this. The end of the motion always produces a lower force than the beginning during testing, whereas the strength curves get increasingly stronger as the leverage gets better. This factor eliminates most joints for testing the length tension contribution.

Two movements that have the same muscles working with equal counterforce throughout the whole range of motion are elbow extension (triceps) and lateral adduction of the upper arm (pectorals). These anatomical strength curves can be followed by most people, so there is no good evidence that the calculated curves must be changed due to muscle length. If there is any validity to the past research, it appears to have little or no use when dealing with the total human body.

TOTAL BODY STRENGTH CURVES

Using the procedure as outlined for the Hip Flexors, the strength curves are presented for all joints of the body. (Figures 5 through 10). Using these data with the knowledge that the counterforce changes with exercise machine designs, a better exercise program can be designed for general body balancing of the musculature.

REFERENCES

1. Carter, B., Morehead, J., Wolpert, S., Hammerschlag, S., Griffiths, H., and Kahn, P. 1977. Cross Sectional Anatomy Computed Tomography and Ultrasound Correlation. Appleton-Century-Crofts, New York, NY.

2. Clarke, H. H. 1966. Muscular Strength and Endurance in Man. Prentice-Hall, Inc., Englewood Cliffs, NJ.

3. Eycleshymer, A. C. and Schoemaker, D. M. 1938. A Cross-Section Anatomy. Appleton-Century-Crofts, Inc., New York, NY.

4. Gordon, A. M., Huxley, A. F., and Julian, F. J. 1964. The Length-Tension Diagram of Single Vertebrate Muscle Fibers. J. Phy. 171: 28-30 p.

5. Gordon, M. S. 1977. Animal Physiology : Principles and Adaptations. 3rd ed. Mac Millan Pub. Co., Inc., New York, NY.

6. Hill, A. V. 1970. First and Last Experiments in Muscle Mechanics. Cambridge U. Press.

7. Steindler, A. 1955. Kinesiology of the Human Body Under Normal and Pathological Conditions. Charles C. Thomas, Springfield, IL.