Strength Curve Analysis

The purpose of this section is to assist clinicians in learning how to interpret test results obtained using MedX evaluation and rehabilitation equipment. The evaluation of strength curves is necessary for health care professionals who wish to use MedX machines as part of their rehabilitation programs. The information that is presented in a patient's strength curve(s) can be used for many purposes, eg. normative comparisons, exercise prescription, confirmation of abnormalities, marking progress, etc. Furthermore, it is often necessary to present this information to patients, lawyers, rehabilitation specialists, insurance adjustors, etc. in a clear, concise manner.

General Considerations

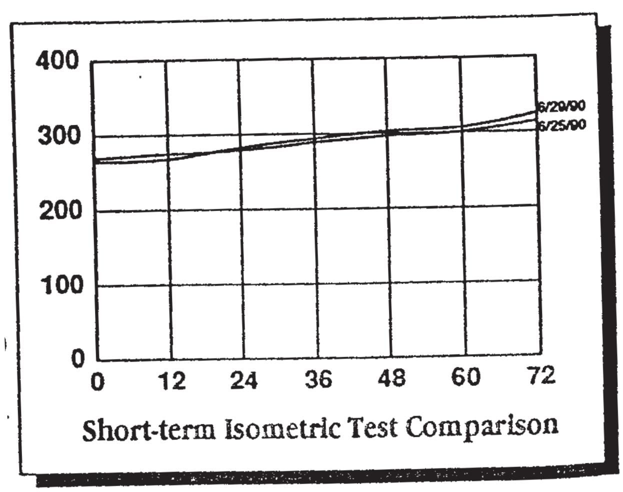
There are at least three basic considerations to keep in mind when evaluating patient strength curves:

1) Be reasonable in your expectations. Realize that you will be dealing with patients whose efforts may vary depending upon their pathology, motivation, mood, etc. You can't expect perfect test results all of the time.
2) You need to have more than one strength curve in order to make objective evaluations concerning test reliability and validity.
3) Look at all of the Information that is presented to you, including; dates, times, torque values, remarks, shape of the curves, 24 hr. history, etc., in order to make a comprehensive and meaningful interpretation.

I. Establish Reliability

The initial step in interpreting strength curves is to determine whether or not the patient has produced valid test results. Without an accurate and reliable test, there is no basis for determining the characteristics of a strength curve or evaluating the effects of a rehabilitation program. To establish reliability, the clinician should compare two or more strength curves obtained from the patient. There are three types of comparisons that can be made: 1) Short-term comparisons, 2) Long-term comparisons, and 3) Comparisons between strength curves obtained during a Fatigue Response Test. The criteria for establishing reliability vary depending upon the type of comparison:

1. Short-term Comparisons
This involves the comparison of two or more maximal isometric strength tests separated by a relatively short time span (from72 hours to 2 weeks). When comparing short-term measurements of strength, the following criteria should be used to establish reliability:



Short-term Isometric Test Comparison

a. Shape of the Strength Curve — The shape (slope) of the curves should be similar. If abnormalities in the shape of the curve are present, they should repeat from one test to another at the same angles within the ROM.

b. Torque Values — In addition to the shape of the curves, the torque values at each angle of measurement should also be similar. However, a patient's strength may vary from one day to another. The acceptable allowance for strength variation from test to test is approxirnately: ±10-20% at each angle of measurement. For example, if a torque value of 200 ft-lb was obtained at a given angle during Test 1, the torque value from Test 2 should fall between 160 and 240 ft-lb for that same measurement angle. If the variation in torque is greater than ±20% at more than two angles of measurement, the strength curve should be considered unreliable. In this situation, additional strength curves should be obtained from the patient until reliability is established.

NOTE: Healthy, asymptomatic subjects are known to demonstrate a ±10-I5% variation in strength in short-term test-retest situations. Based upon clinical observations, we recommend increasing this value by 5% for the patient population (i.e. ±20%).

2. Long-term Comparisons

This involves the comparison of two or more maximal isometric strength tests separated by a substantial time span (4,8, 12, 2O weeks, etc.). Typically, long-term measurements of strength are analyzed to determine the effects of a treatment program. When interpreting long-term measurements of strength, one criterion should be used to establish reliability:

a. Shape of the Curves — If the patient demonstrates a relatively normal strength curve at the beginning of a rehabilitation program, post-treatment strength curves should also be similar in shape. However, if the patient demonstrates an abnormal strength curve at the beginning of a rehabilitation program, allowances should be made for the correction of strength deficiencies at specific joint angles over time, and for a flattening of the strength curve as treatment progresses (effect of cam). If significant changes in the shape of the patient's strength curve occur, it is recommended that another isometric test be administered within several days to establish reliability. In this case, the clinician can then use the reliability criteria for short-term comparisons of strength. For example, if the shape of a patient's 12-week strength curve had changed dramatically from baseline measurements, the clinician should test the patient again at 13 weeks. The strength curves for weeks 12 and 13 can then be compared with the shape or the strength curves and force values in mind.

3. Fatigue Response Test Comparison

This involves the interpretation of a fatigue response test (FRT) in which a measurement of maximal isometric strength is compared with a measurement of maximal isometric strength performed immediately following a set of dynamic repetitions performed to volitional muscular fatigue. In order to establish the reliability of this test sequence, one criterion should be used:

a. Shape of the curves — The two strength curves should be similar in slope and appear parallel. There should be a consistent amount of fatigue throughout the entire ROM. On occasion, a patient will fail to generate reliable test results at one or more angles of measurement. In this circumstance, the measured fatigue at the unreliable angle(s) will be different than that demonstrated throughout the rest of the ROM.

II. Compare the Strength Curve to Normal

Comparing a patient's strength curve to established norms is important in order to identify functional deficits and to evaluate the effectiveness of a treatment program. Variables to consider when comparing a curve to the 'norm' include:

1. Range-of-Motion — In general, healthy, untrained subjects demonstrate a full ROM of 72° on the lumbar extension machine; 126° on the cervical extension machine. Since factors other than pathology may affect joint flexibility (i.e., distribution of body fat), ROM should not be considered 'normal' or 'abnormal'. The terminology we recommend using to describe a patient's ROM is either 'full' or 'limited'.

2. Shape of the Curve — The shape of the strength curve for a healthy, untrained subject is linear and descending from flexion to extension. An abnormality will be visibly noted as a peak or trough.

3. Strength Values — A patient's absolute and relative (torque/bodyweight) strength values should be compared to age and gender-specific normative values obtained from healthy, untrained individuals.

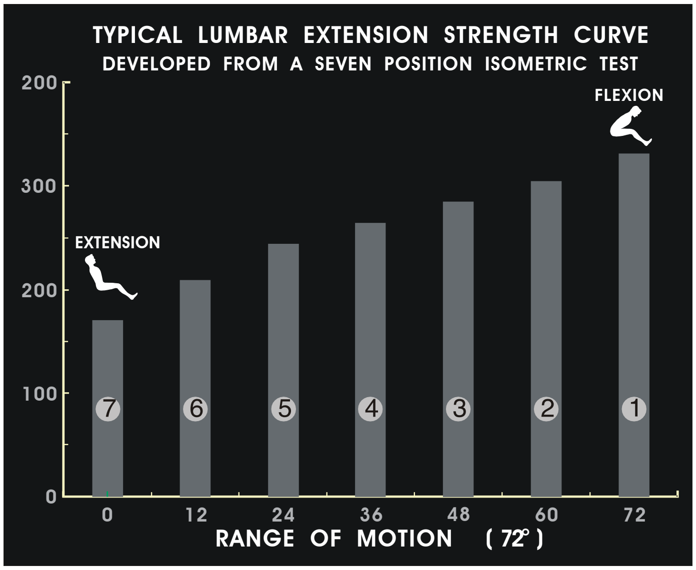
4. Flexion:Extenslon Strength Ratio — The flexion:extension ratio expresses strength in the fully flexed position relative to strength in the fully extended position. For example, a patient who has produced 250 ft.-lbs. of torque at 72° of lumbar flexion, and 100 ft.-lbs. at 0º, would have a flexion:extension ratio of 2,5:1 (250÷100). This means that the patient is 25 times stronger in their fully flexed position than in their fully extended position. Flexion:extension ratios for healthy, untrained males and females are presented in Table 1.

TALBE 1: Average Male and Female Strength Values

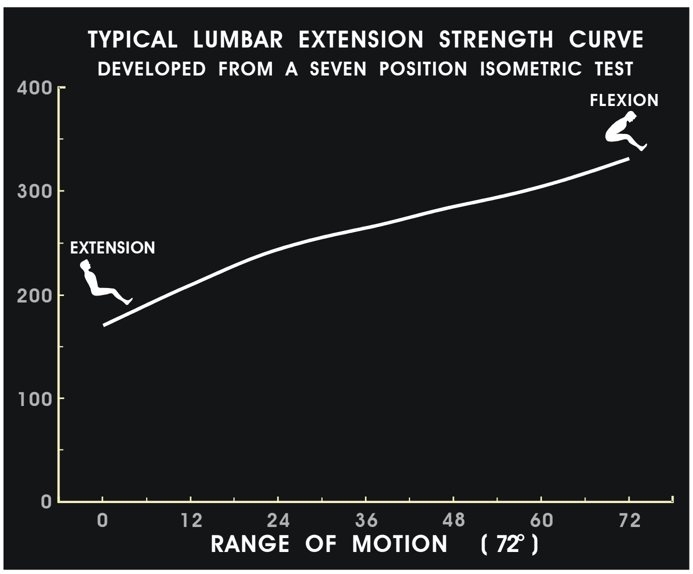
Movement	Gender	Age	Flexion:Extension Ratio
Lumbar Extension	Male	18-35 yr	2.0:1
		36-59 yr	2.3:1
		60-78 yr	2.1:1
	Female	18-35 yr	1.9:1
		36-59 yr	1.9:1
		60-78 yr	1.9:1
Cervical Extension	Male	18-60 yr	1.6:1
	Female	18-60 yr	1.3:1

*Flexion is 72º for Lumbar, 126º for cervical. Extension is 0º for lumbar and cervical

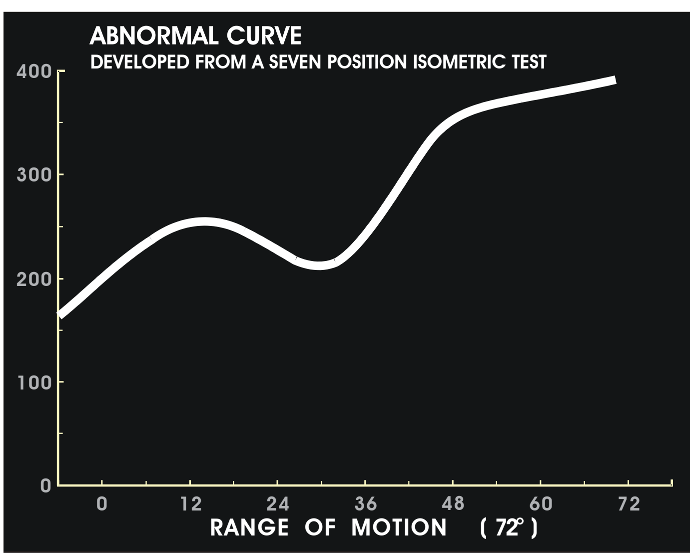
STRENGTH CURVES



Having performed static tests (isometric contractions) in several positions throughout a full range of movement, the monitor shows a bar-graph of torque in each position. A normal ratio of functional strength would show the highest level of torque in the flexed position (right) and the lowest level in the extended position (left), with proportionate levels in intermediate positions.



Based upon the torque measured in several positions, the computer will interpolate strength throughout the full range of movement. If the ‘stored energy” option is selected, the monitor show not just functional torque but also a second line designating NMT (net muscular torque), distinguished by cifferent colors.



A normal “curve” is actually closer to being a straight line. The patient who produced the test result at left indicates a marked abnormality at approximately 30 degrees.

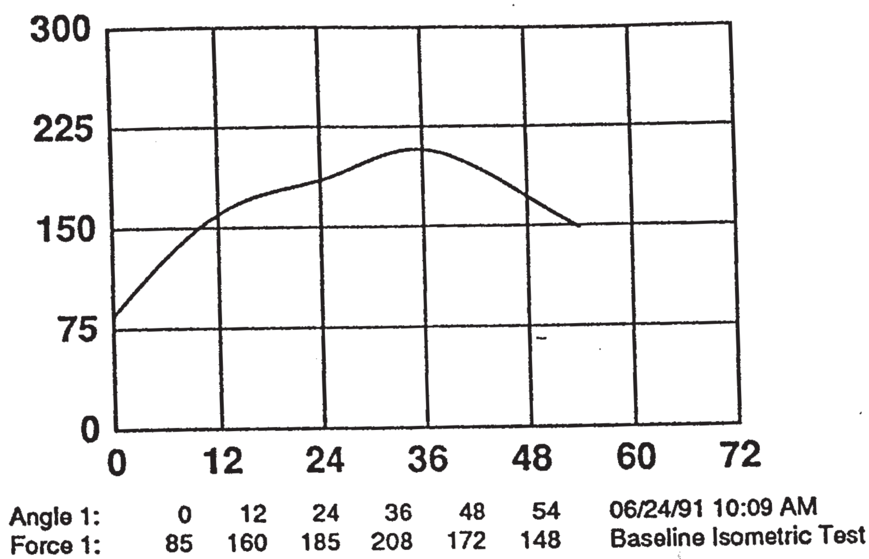
Potential for Strength Improvement

The patient's potential for strength development can be evaluated by comparing the patient's strength curve to the normal strength curve for healthy untrained individuals. When doing so, keep in mind that the ideal flexion to extension ratio is considered to be 1.4:1 (lumbar and cervical extension). Also, be sure to consider the patient's initial level of strength since relative improvements in strength are affected by training status.

Example: The following strength curve was obtained from a 30-year-old male patient at the start of his treatment program. Assume the short-term reliability has been established.

When compared to the age-matched average male strength curve, the patient's curve demonstrates the following characteristics:

Limited ROM
1) Below average strength
2) Two angles (54°, 48") disproportionately weak (abnormality)



Given the available information, it would be reasonable to assume that this patient will demonstrate fairly large increases in strength throughout the entire ROM. The greatest improvements would be anticipated at the 0, 48, and 54 degree positions. It would also be reasonable to assume that this patient will experience an increase in ROM, specifically in the flexed positions.

III. Determine the Patient's Fatigue Characteristics

The fatigue characteristics of the lumbar and cervical extensor muscles are assessed by comparing a measurement of maximal isometric strength (PRE FRT), to a measurement of isometric strength immediately following a set of dynamic exercise to volitional muscular fatigue (POST FRT). The average level of fatigue throughout the entire ROM is called the fatigue index, and is calculated using the following equation:

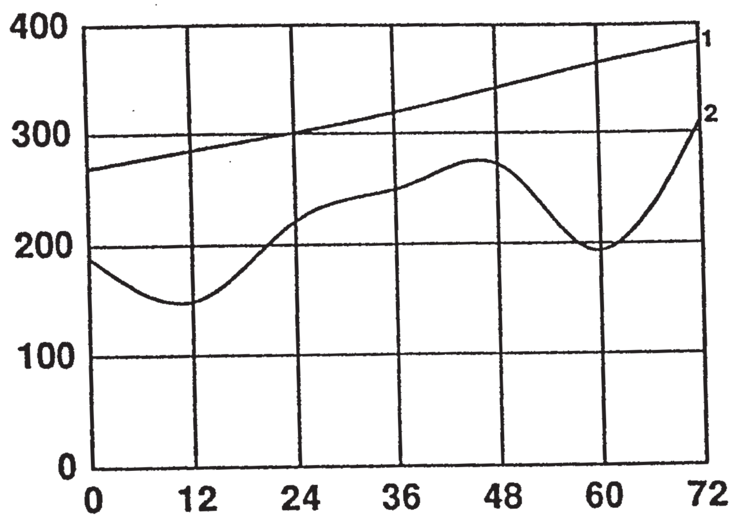
[(Sum PRE FRT - Sum POST FAT) / Sum PRE FRT] X 100 = _% avg fatigue

Example:

Sum PRE FRT (72°, 60°, 48°, 36°, 24°, 12°,0") - 2346
Sum POST FRT (72°, 60°, 48°, 36°, 24°, 12°,0") -1727
(2346-1727)/2346] x 100 = 26% average fatigue

As stated previously, a patient will sometimes fail to demonstrate reliable test results at one or two angles of measurement. When this occurs, omit the angles that appear unreliable from your calculations and use either a sum of 5 or 6 angles to determine the fatigue index.

For example, in the graph below, the measured fatigue at the 60- and 12-degree positions is disproportionate compared to the measured fatigue at the other five test positions. In this case, the force values at these two angles of measurement (60 and 12 degrees) would be excluded from your calculations.



Angle 1:	0	12	24	36	48	60	72	11/17/91 01:55 PM
Force 1:	270	284	296	314	346	367	385	PRE FRT
Angle 2:	0	12	24	36	48	60	72	11/17/91 02:09 PM
Force 2:	190	152	228	251	267	195	301	POST FRT

Sum PRE FRT (72°, 48°, 36°, 24°, 0°) = 1611
Sum POST FRT (72°, 48°, 36°, 24°, 0°) = 1237

[(1611- 1237)/1611] x 100 = 23% average fatigue

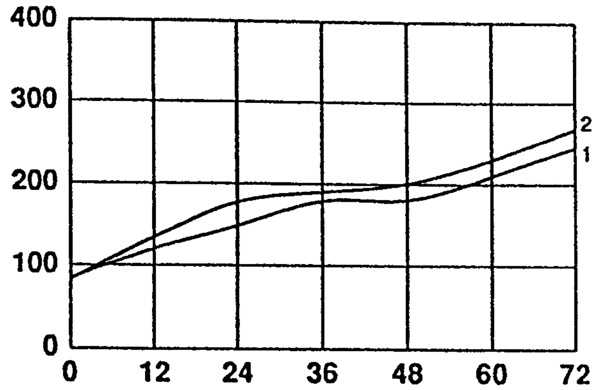
IV. Exercise Prescription

The information from a patient's strength curve(s) may be used to formulate the patient's exercise prescription. If the patient is not demonstrating improvements in strength or symptoms, the exercise prescription may need to be altered. In particular, the fatigue index can be used to establish a desired repetition range and training frequency when a patient fails to demonstrate progress with the standard treatment protocol. See "Clinical Fatigue Response Testing.'

Periodic re-evaluation of a patient's strength curve(s) is required in order to assess the effectiveness of the treatment program (long-term strength comparisons). Indicators of a successful treatment program include a significant increase in full ROM strength and a flattening of the patient's strength curve following 12 to 20 weeks of treatment. Research with healthy subjects has shown that the average lumbar extension flexion:extension strength ratio reached an 'ideal' ratio of 1.4: 1 following 20 weeks of training. Eventually, the patient may reach his or her potential for strength development. Indicators of a normal ending point in a rehabilitation program include a plateau in the patient's absolute level of isometric strength and dynamic training weight (no further increase in strength with continued training). When this occurs, a program of supportive care is recommended.

Study Problem #1

The following graph was obtained from a 200-pound, 35-year-old male patient during his first and second visits to the clinic:



Angle 1:	0	12	24	36	48	60	72	06/21/91 03:33 PM
Force 1:	84	120	148	179	180	210	245	Initial Isometric Test
Angle 2:	0	12	24	36	48	60	72	06/28/91 03:40 PM
Force 2:	83	134	177	190	201	230	268	Second Isometric Test

1. Does this subject demonstrate reliable test results? Use a short-term comparison to compare the curves in the figure (Hint: Calculate the variation between the two tests at each test angle, and determine if this is acceptable).

2. Does this Patient demonstrate full or limited ROM?

3. Are the shapes of the curves normal or abnormal?

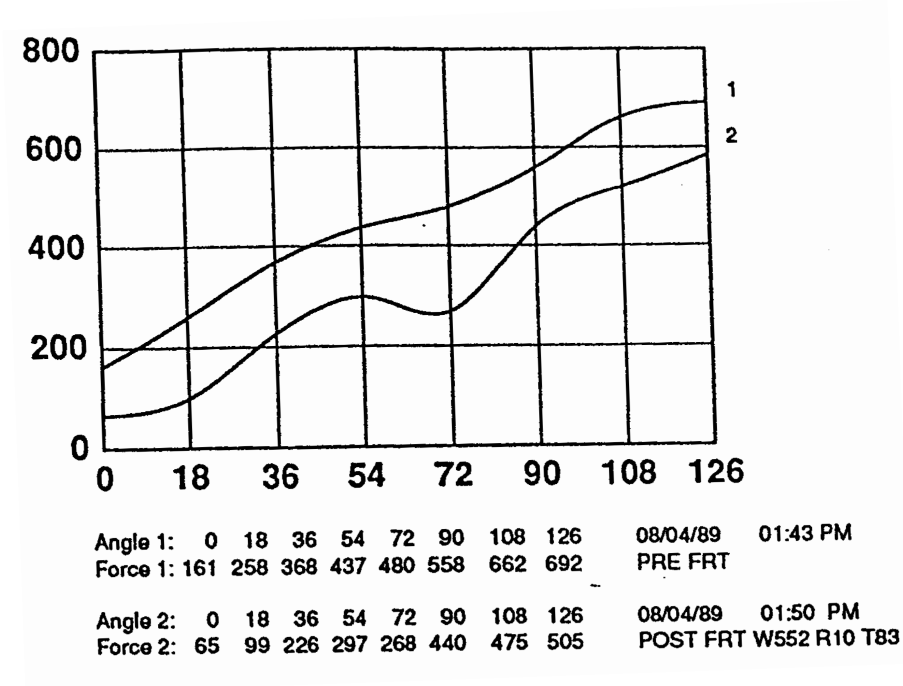
4. Calculate the flexion:extension ratio for the Second Isometric Test. What does this indicate?

5. Determine the percentile ranking at each measurement angle for this patient's ~ strength (use the Second Isometric Test).

6. Calculate this patient's relative strength at each measurement angle (use the Second Isometric Test).

Study Problem #2

The following graph presents the results of a Fatigue Response Test performed by a 200-pound, 28-year-old male patient:



1. Compare this patient's absolute strength at each measurement angle to the average, healthy male (use Pre FRT).

2. Is the shape of this patient's strength curve (PRE FRT) normal? Why/why not?

3. Compare the patient's flexion: extension ratio (PRE FRT) to normal. What does this indicate?

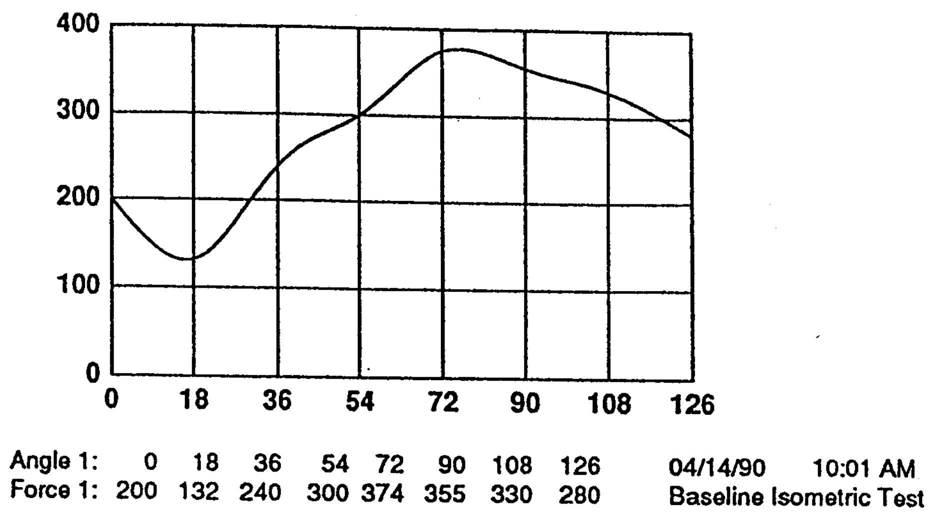
4. In terms of fatiguability, does this patient demonstrate reliability throughout the entire ROM?

5. Calculate this patient's fatigue index. Assuming that the patient bas not satisfactorily responded to the standard protocol, how would you alter the exercise prescription (repetition range; frequency)?

6. Describe any changes you would expect to see in the patient's strength curve consequent to a 12 to 20 week rehabilitation program.

Study Problem #3

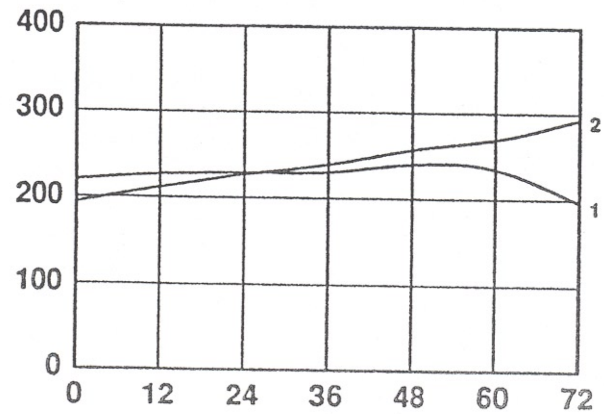
The following graph was obtained from a 52-year -old male patient (assume that short term reliability has been established):



1. Would you consider this a normal or abnormal strength curve? Why?
2. Calculate the flexion to extension ratio. Does this ratio accurately describe the shape of the curve?
3. Describe this patient's potential for strength development based on the information presented.

Study Problem #4

The following two strength curves were obtained from a 130-pound, 24-year-old female patient prior to and following 12 weeks of treatment:



Angle 1:	0	12	24	36	48	60	72	01/22/91 02:22 PM
Force 1:	220	227	229	230	240	235	197	Baseline Isometric Test
Angle 2:	0	12	24	36	48	60	72	04/19/91 03:10PM
Force 2:	194	212	227	239	257	269	293	12 WK Isometric Test

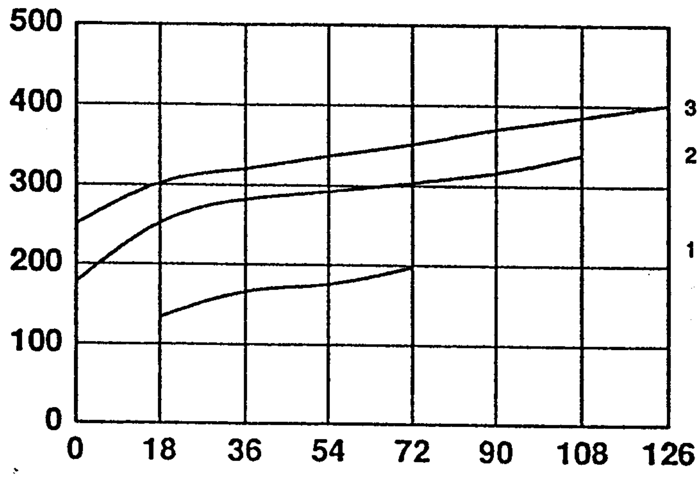
1. Compare this patient's strength curve following 12 weeks of treatment to a healthy, untrained female (consider all normative variables, ie. Shape, ROM, absolute and relative strength, flex/ext ratio).

2. Calculate this patient's percent improvement in strength at the 72° position.

3. If this patient were free of pain at the time of her 12 WK test, would you recommend that she continue in the rehabilitation program? Why/why not?

Study Problem #5

The following graphs were obtained from a 183-pound, 31-year-old male patient during his 12-week rehabilitation program:



Angle 1:		18	36	54	72				09/19/91 02:30 PM
Force 1:		134	166	176	198				INITIAL IM TEST
Angle 2:	0	18	36	54	72	90	108	126	11/17/91 01:55 PM
Force 2:	177	252	282	292	304	317	339		8 WK IM TEST
Angle 3:	0	18	36	54	72	90	108	126	12/20/91 12:37 PM
Force 3:	250	302	321	337	352	371	386	402	12 WK IM TEST

1. After 12 weeks of rehabilitation, compare this patient’s flexion:extension ratio to normal.

2. Calculate the patient’s average strength increase over the 12 week rehabilitation program? (Hint: This can only be calculated relative to the patient’s initial ROM)

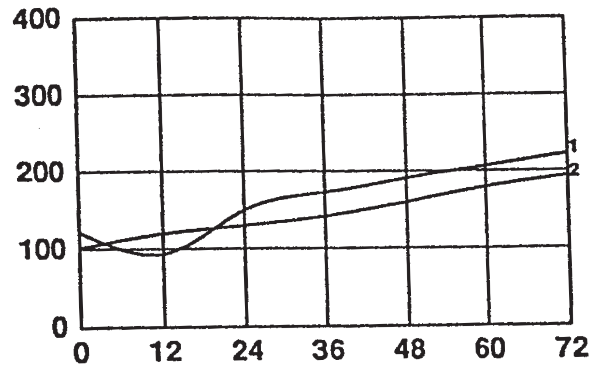
3. How much has this patient’s ROM improved since the initial testing? (Expressed as a percentage).

Study Problem #6

The following graph presents the results of a Fatigue Response Test obtained from a 37-year -old female patient

1. Calculate this patient's fatigue index.

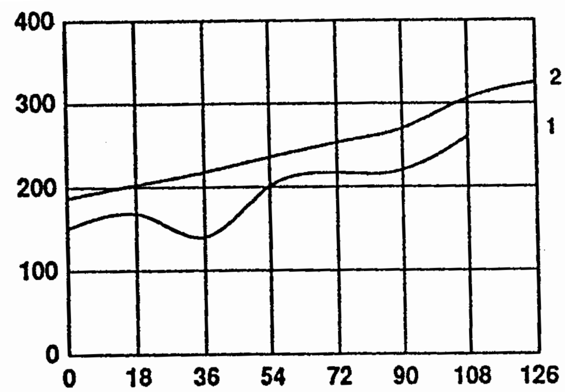
2. Determine this patient's absolute strength percentile ranking at all reliable test angles (use PRE FRT).



Angle 1:	0	12	24	36	48	60	72	07/07/90	04:41 PM
Force 1:	117	94	150	173	191	207	223	PRE FRT	
Angle 2:	0	12	24	36	48	60	72	07/07/90	04:46 PM
Force 2:	105	120	130	142	160	180	194	POST FRT	

Study Problem #7

The following strength curves were obtained from a 44-year-old male patient prior to and following 12 weeks of treatment:



Angle 1:	0	18	36	54	72	90	108	126	03/10/90	09:05 AM
Force 1:	151	168	140	201	217	220	260		Baseline Isometric Test	
Angle 2:	0	18	36	54	72	90	108	126	06/12/90	10:14 AM
Force 2:	187	203	218	236	253	270	306	325	12 Weeks	

1. How much has this patient's ROM improved since initial testing? (expressed as a percentage)

2. Calculate the average percent improvement in strength throughout the ROM from the Baseline Isometric Test to 12 WK.

Strength Curve Reliability Summary

Short Term Comparisons:

Long Term Comparisons:

Measurements of Fatiguability:

2. Shape of the Curves

Strength Curve Interpretation and Formulas

I. Flexion to extension ratio (flex/ext ratio)
The flex/ext ratio is used to describe the relationship in strength from the flexed to extended position.

$$\text{Flex/Ext ratio} = \frac{\text{Torqpe (ft-lb) produced in fully flexed position}}{\text{Torque (ft-lb) produced in fully extended position}}$$

II. Relative strength
When expressing a relative strength measurement, you are describing a patient's torque production relative to their body weight. This is particularly important when a patient's body weight falls above or below normal values.

$$\text{Relative Strength} = \frac{\text{Angle-specific torqpe (ft-lb)}}{\text{Patient's body weight (lbs)}}$$

III. Fatigue Index (Inroad)
The fatigue index measures the change in strength (expressed as an average percentage) from a pre FRT to a post FRT.

$$\text{Fatigue Index} = \frac{\Delta\text{ (Sum Pre FRT. Sum Post FRT)}}{\text{Sum Pre FRT}} \text{ X } 100\%$$

*Note: this calculation should only be used after test reliability has been established

IV. Variation of Torque at One Angle of Measurement
The angle variation describes, as a percentage, the difference in strength between two test measurements.

$$\text{Angle Variation} = \frac{\Delta\text{ (T1, T2)}}{\text{criterion (usually T1)}} \text{ X } 100\%$$

Ex. T1 at 72° of lumbar flexion = 320 ft-lb
T2 at 72° of lumbar flexion = 385 ft-lb

$$\text{Angle Variation} = \frac{\text{(385 - 320) ft-lb}}{\text{320 ft-lb}} \text{ X } 100\% = 20\%$$

V. % Improvement in Strength at One Test Angle
It is often useful to describe a patient's change in strength over the course of the rehabilitation program as a percentage of improvement.

$$\%\text{ Improvement in Strength} = \frac{\Delta\text{ (T1, T2)}}{\text{T1}} \text{ X } 100\%$$

Ex. Baseline measurement at 720 of lumbar flexion = 134 ft-lb
12 wk measurement at 720 of lumbar flexion = 263 ft -lb

$$\%\text{ Improvement in Strength} = \frac{\text{(263 - 134) ft-lb}}{\text{134 ft-lb}} \text{ X } 100\% = 96\%$$

VI. Average % Strength Change*

Changes in strength can also be described as an average % improvement throughout a patient's ROM.

$$\text{Average \% Strength Improvement} = \frac{\Delta\ (\text{Sum T1, Sum T2})}{\text{Sum of T1}} \times 100\%$$

Ex. sum of baseline torque values = 2257 ft-Ib
sum of 12 wk torque values = 2897 ft-Ib

$$\text{Av. \% Strength Improvement} = \frac{(2897 - 2257)\ \text{ft-Ib}}{2257\ \text{ft-Ib}} \times 100\% = 28\%$$

*Note: Make sure average % change is calcualted through similar ROM from T1 to T2.

VII: % Change in ROM

This calculation describes a patient's relative (%) change in ROM between two isometric tests.

$$\text{\% Change in ROM} = \frac{\Delta\ (\text{T1 ROM, T2 ROM})}{\text{T1 ROM}} \times 100\%$$

Ex. Baseline demonstrated ROM = 54° of lumbar flexion
4 wk demonstrated ROM = 63° of lumbar flexion

$$\frac{(63 - 54)^\circ}{54^\circ} \times 100\% = 7\% \text{ Increase in ROM}$$

VIII: ROM Deficit Compared to Normal

$$\text{ROM Deficit} = \frac{\text{Normal (full) ROM - Patient's Demonstrated ROM}}{\text{Normal (full) ROM}} \times 100\%$$

Ex. Baseline ROM = 54° of lumbar flexion
Normal ROM = 72° of lumbar flexion

$$\frac{(72 - 54)^\circ}{72^\circ} \times 100\% = 25\% \text{ Deficit in ROM}$$

IX. Strength Deficit Compared to Normal

Strength Deficit =

$$\frac{\text{avg (norm) angle specific torque - patient's angle specific torque}}{\text{avg (norm) angle specific torque}} \times 100\%$$

NOTE: Whenever you are calculating the percent change between two measurements, the same general formula applies:

$$\frac{\text{Difference between test measurements}}{\text{Criterion Measurement}} \times 100\%$$