Technical Report

Material Properties of Thera-Band Tubing

Background and Purpose. Thera-Band Tubing has been used in rehabilitation to provide resistance for exercise and splinting. However, the forces required to stretch the tubing have not been thoroughly quantified. Therefore, the therapist cannot assess, with certainty, how much force is applied when using a given length and type of Thera-Band Tubing. The purpose of this study was to quantify the material properties of Thera-Band Tubing. Methods. Force versus percentage of strain for all types of Thera-Band Tubing was measured during elongation in a mechanical testing machine. Results. The material is very compliant and displays nonlinear behavior in the initial stretching phase and linear behavior after 50% elongation. Discussion and Conclusion. From the data obtained in this project, plots that can provide the therapist with information about the forces needed for exercises with Thera-Band Tubing were generated. These data should allow therapists to make better choices about which size of tubing to use for each patient. [Patterson RM, Stegink Jansen CW, Hogan HA, Nassif MD. Material properties of Thera-Band Tubing. *Phys Ther.* 2001;81:1437–1445.]

Key Words: *Material properties, Mechanics of elastic materials, Rehabilitation, Strength training.*

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Elastic tubing is a common material used for resistance training.[1–3] Patients use it to provide resistance for exercise and to increase range of motion after trauma.[4,5] The tubing also is used in splints to provide controlled stretching and strengthening of muscle tendon units and joints.[6] Exercises with elastic tubing are used for home training and allow large numbers of arcs of motion with both concentric and eccentric muscle contractions.[7] Mikesky et al[1] determined that a home-based resistance-training program for older adults (average age=71.2 years) using elastic tubing could serve as a practical and effective means of improving muscle strength. Authors have advocated the use of tubing for shoulder injuries in conjunction with other treatments or in isolation.[4,5] Similarly, Brotzman and Brasel[8] recommended similar strategies for ankle injuries. One disadvantage of elastic resistance is the progressively increasing force required as the material stretches. Near the end of the range of motion, an individual may not be able to complete the desired motion, as muscles may be weaker because they may be in a shortened position at the point at which the resistance is greatest.

Tubing is also used as a component in splints.[6] The tubing is used to generate a consistent and controlled force that can be customized to the needs of the patient to provide a resistive force for exercise or to provide a low- or high-load stretch. We believe that the quantification of the force-generating properties of the material is important because, on a theoretical basis, inappropriate use of the material could be harmful. Too much force, torque, or pressure may cause inflammation, scarring, or deformity; too little force actually may prevent the patient from reaching full rehabilitation potential. In addition, not all elastic materials provide similar tensions. Because the physical properties of elastic assist devices influence the amount of tension generated, we believe that the choice of material is extremely important and should be based on the specific needs of the patient.[6,9]

Other investigations[1,5,10] examined the force-generating potential of fixed lengths of Thera-Band Tubing* at one rate of elongation. Tafel et al[11] documented the force versus percentage of elongation of 5 colors of tubing (Exertubing) that appear to have been distributed by Sammons Inc.† However, they did not investigate the effects of various lengths, strain rate, repeatability, cyclic loading, or preconditioning on the tubing. Fess and Phillips[6] investigated the force-versus-displacement properties of several elastic materials, including Thera-Band Tubing, used with splints. However, they did not provide comparisons between different types of Thera-Band Tubing. Mikesky et al[1] quantified some aspects of Thera-Band Tubing by determining the force versus displacement relationships for 5 types of tubing. This quantification was accomplished by stretching 102-, 305-, and 711-mm lengths of white, black, blue, green, and red tubing. Only a force-versus-displacement graph for the 305-mm-long tubing was reported. Hintermeister et al[10] quantified elastic resistance of Thera-Band Tubing dur-

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ing knee rehabilitation exercises. They recorded the average force generated during the exercises but did not provide information about how much the material displaced (stretched) during the motion. Hughes et al[5] tested 6 different colors of Thera-Band Tubing during a shoulder exercise. They provided tension versus percentage of band length changes for each color and concluded that Thera-Band Tubing provides a linear response during shoulder exercise. However, they tested only one length, 116.8 cm (~46 in), of tubing. Simoneau et al[12] tested 0.2- and 0.4-m lengths of Thera-Band Tubing in a constant-speed linear actuator.[‡] They stretched each piece 500 times at a rate of 108 cm/min and reported tensile forces at 100% and 200% strain. They, however, tested only 3 types of Thera-Band Tubing and reported only data for 100% and 200% strain.

The Hygenic Corp markets 8 types of Thera-Band Tubing with increasing diameter and wall thickness (tan [extra thin], yellow [thin], red [medium], green [heavy], blue [extra heavy], black [special heavy], silver [super heavy], and gold [max]). The company markets them in order of resistance but offers no detailed material property specifications.

The purpose of this study was to determine in more detail the material properties of Thera-Band Tubing so that the resistance provided by the tubing for any particular exercise can be predicted. Six aspects of the force-generating potential (material properties) of Thera-Band tubing were investigated: (1) the effect of the original length of the sample, (2) the effect of prestretching, (3) the effect of the rate of loading, (4) the repeatability, (5) the effect of cyclic loading, and (6) the loading versus unloading properties. With this information, a therapist can prescribe a more precise exercise program for each patient through knowledge of the resistance provided by the Thera-Band Tubing on the basis of the color and the initial and final lengths of the tubing.

Material and Methods

Study Design

Figure 1 depicts the strategy for the study design. The primary objectives of the study were to determine the material properties of the tubing and to create a chart depicting the force change associated with elongation of the material. In order to do that, 3 questions had to be answered: (1) Do samples of different lengths have the same properties? (2) Does the material behave differently if it is prestretched? and (3) Does the material behave differently if it is stretched slowly or quickly?

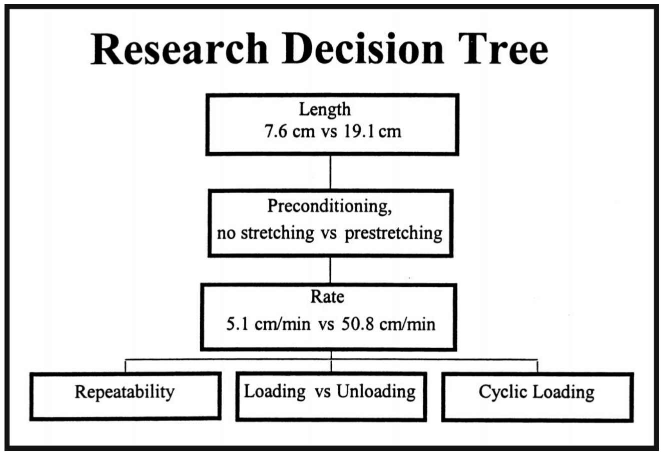

Figure 1.
Design decision chart.

After these questions were answered, issues of repeatability, loading and unloading properties, and the effects of cyclic loading of the material could be investigated.

Samples

Six types of Thera-Band Tubing (yellow [thin], red [medium], green [heavy], blue [extra heavy], black [special heavy], and silver [super heavy]) from the same lot (box) were tested. The samples were new out of the box and were never stretched prior to testing.

Instrumentation

Custom-made metal fittings (Texas A&M University, College Station, Tex) were inserted into both ends of the tubing, fastened with plastic cable ties, and mounted into a standard material testing machine. Unless otherwise noted, tests were conducted with an Instron model 1125 machine,[§] which is a standard servo-motor-driven screw-actuated load frame with closed-loop position control. The initial length of a sample was measured between the ties on the ends.

Calibration

In order to confirm the accuracy of the load measurements, the average force reading of the Instron was measured for 150 seconds using 2 load cells: a 20-lb (89-N) load cell for low forces and a 100-lb (445-N) load cell for higher forces. Because the Instron is calibrated in English units, all measurements will be reported in pounds, with the corresponding SI units in parentheses. Three scenarios were tested: with no weight attached, after hanging a 10-lb (44.5-N) weight, and after hanging a 20-lb (89-N) weight. The respective results, reported as the average ± standard deviation, for the 20-lb load cell were 0.004±0.09 lb (0.018±0.4 N), 10.07±0.01 lb

‡ Industrial Devices Corp, 64 Digital Dr, Novato, CA 94949.

§ Instron Corp, 100 Royall St, Canton, MA 02021-1089.

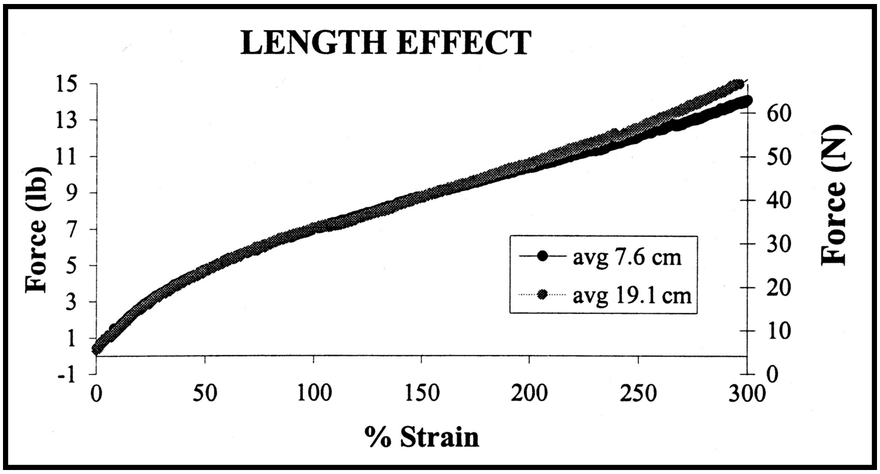

Figure 2.
Average force for 7.6-cm (black line) and 19.1-cm (gray line) black tubing.

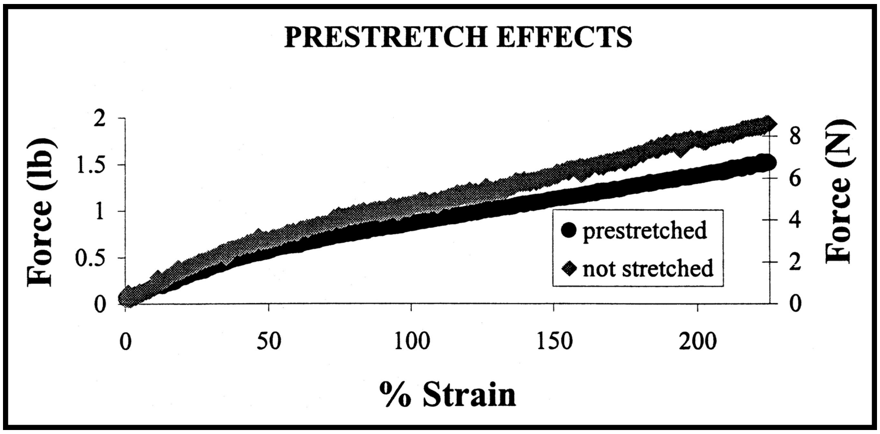

Figure 3.
Average prestretched and unstretched values for 7.6-cm yellow tubing.

(44.81±0.05 N), and 19.99±0.00 lb (88.96±0.00 N). The respective results for the 100-lb load cell were 0.08±0.04 lb (0.36±0.18 N), 10.09±0.03 lb (44.9± 0.13 N), and 20.17±0.07 lb (89.8±0.331 N). Thus, the Instron output had a measurement error of less than 1% (the worst error for the 20-lb load cell was 0.7%, and that for the 100-lb load cell was 0.9%).

Procedure

The Thera-Band Tubing was tested in uniaxial tension at various loading rates under displacement control. The force and displacement data were recorded at 5 Hz (5 data points per second) on a computer. Samples of yellow, red, green, blue, black, and silver tubing were studied. The load cell of the test machine allows the selection of different maximum load levels. Thus, the samples of smaller tubing (yellow, red, and green) were tested using a 20-lb load cell, and the samples of larger tubing (blue, black, and silver) were tested using a 100-lb load cell. Because the material is so elastic and can be stretched so much and because the travel of the Instron machine is limited to 60.96 cm, shorter lengths of material had to be tested in order to create strain levels similar to those of practical relevance (ie, up to several hundred percent).

Length effect. Five samples each of 7.6 cm and 19.1 cm of yellow and black tubing were tested at one strain rate. Yellow tubing and black tubing were used to represent small- and large-diameter tubing. Because of the different lengths, 2 displacement rates had to be used to result in equal strain rates for the 2 lengths. A rate of 5.1 cm/min was used for the 7.6-cm samples, and 12.7 cm/min was used for the 19.1-cm samples; these values created a common strain rate of 67%/min. This rate was intended to be essentially quasi-static in order to avoid potential rate effects and to allow us to focus primarily on length effects.

Prestretching. Load-versus-displacement plots for 5 samples of 7.6 cm and 19.1 cm of yellow and black tubing were recorded at a constant strain rate. Yellow tubing and black tubing were used to represent small- and large-diameter tubing. One sample was cut and tested without prestretching, then 3 more were tested the same way, and finally the fifth sample was manually stretched 20 times and tested.

Loading rate. Load-versus-displacement plots for 2 samples of 7.6 cm of blue and black tubing were recorded twice at 2 loading rates (5.1 and 50.8 cm/min) in order to compare the quasi-static response with a rate similar to what we believe occurs with actual exercises. The corresponding strain rates were 67%/min and 667%/min, the latter representing a 10-fold increase in rate. Larger tubing was used because smaller tubing slipped out of the custom fittings at higher strain rates.

Repeatability. Load-versus-displacement plots for 2 samples of 7.6-cm yellow and red tubing taken from the same lot (box) of tubing were recorded twice at a loading rate of 5.1 cm/min.

Cyclic loading. Load-versus-displacement plots for 2 samples of 7.6 cm of green tubing were recorded with a hydraulic material testing machine. Green tubing was

Table 1.
Slope and Force Values for Different Lengths of Tubing

Color	Length (cm)	FS[a]	Average Force Difference (N)
Yellow	7.6	0.45	0.09±0.89 (−0.22 to 0.36)
	19.1	0.45	
Black	7.6	0.18	−0.85±1.47 (−5.3 to 9.8)
	19.1	0.18	

[a] FS=force-versus-% strain slope.

Table 2.
Slope and Force Values for Prestretched and Not Stretched Tubing

Color	Length (cm)	Prestretched	FS[a]	Average Force Difference (N)
Yellow	7.6	Y	0.45	−0.98±0.53
		N	0.45	(−1.96 to 1.74)
	19.1	Y	0.13	
		N	0.45	
Black	7.6	Y	0.18	1.47±0.36
		N	0.13	(0.13 to 2.45)
	19.1	Y	0.13	
		N	0.18	

[a] FS=force-versus-% strain slope.

Table 3.
Slope and Force Values for Tubing Tested at Different Rates

Color	Rate (cm/min)	FS[a]	Average Force Difference (N)
Black	5.1	0.13	1.56±0.98 (−0.58 to 3.79)
	50.8	0.18	
Blue	5.1	0.13	0.98±1.07 (−2.14 to 2.45)
	50.8	0.18	

[a] FS=force-versus-% strain slope.

Table 4.
Slope and Force Values After Repeated Trials

Color	Trial	FS[a]	Average Force Difference (N)
Yellow	1	0.45	0.22±0.89 (−0.27 to 0.31)
	2	0.45	
Red	1	0.45	0.4±0.18 (−0.98 to 0.13)
	2	0.40	

[a] FS=force-versus-% strain slope.

selected as representative of elastic tubing with intermediate resistance. Each sample was stretched to a starting point of 15.2 cm (100% strain) and then cycled to 22.9 cm and back to 15.2 cm (stroke control). The cyclic loading thus varied sinusoidally from 100% to 200% strain. The first sample was tested for 1.5 hours at 0.5 Hz (approximately 2,700 cycles) and for 50 minutes at 1 Hz (approximately 3,000 cycles), for a total of 5,700 cycles. The second sample was tested for 1.7 hours at 1 Hz (approximately 5,800 cycles). We used numbers of cycles that we believe are representative of typical patient exercise protocols.[2] Each of 4 different exercises with 10 repetitions 3 times per day for 4 weeks would mean 2,400 cycles of the tubing, and after 9 weeks that schedule would mean 5,400 cycles.

Loading versus unloading. Load versus displacement for 2 samples of 7.6 cm of green, blue, black, and silver tubing was measured during loading of up to 300% strain and then was measured during unloading. Yellow tubing and red tubing were not tested because the tubing slipped out of the custom fittings at strain values of greater than 200%. This problem made it difficult to obtain loading-versus-unloading plots.

Data Analysis

The force-versus-displacement plots were normalized to force-versus-percentage of strain (FS) plots in order to account for tube length on the basis of the following calculations. The percentage of strain was calculated as the change in length divided by the original length, times 100. Average differences in the slopes of the FS curves and the force (analyzed as the force difference between conditions) at each percentage of strain (dependent variable) were analyzed against the independent variables of original length, loading rate, prestretching, repeatability, cycle loading, and loading direction (loading versus unloading) by use of analysis of variance (PC SAS[‖]). Significant differences are reported for $P \leq .05$.

Results

Values for slopes are displayed in SI units, force (newtons) versus percentage of strain (unitless). Graphs depict both English units (force [pounds], left axis) and SI units (force [newtons], right axis).

Length Effect

There were no differences between the FS curves or slopes for the 7.6- and 19.1-cm samples (Fig. 2). Data for the average FS slopes and average forces for the samples at each percentage of strain (up to 200% strain) for yellow and black tubing are shown in Table 1.

Prestretching

There were differences between the FS curves or slopes for the prestretched and unstretched samples. Figure 3 shows that prestretched material has a lower slope and produces lower forces at higher percentages of strain. There were no differences in the average force at each

[‖] SAS Institute Inc, PO Box 8000, Cary, NC 27511.

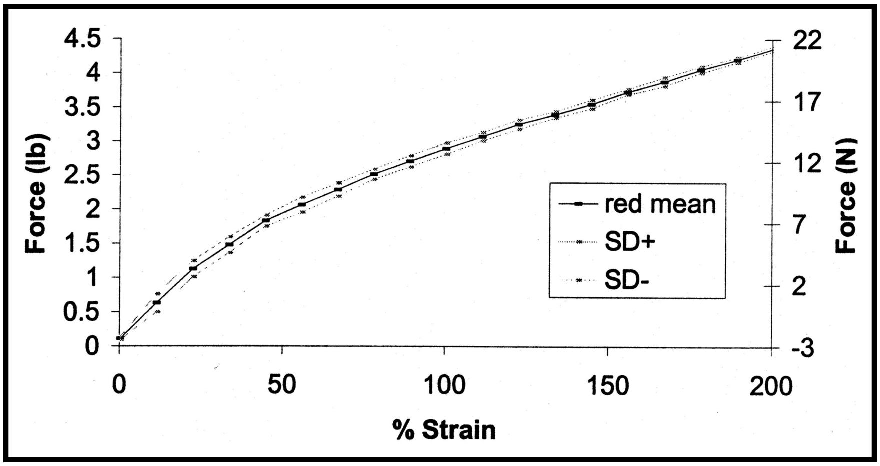

Figure 4.
Graph showing mean and standard deviation for 2 trials of red tubing.

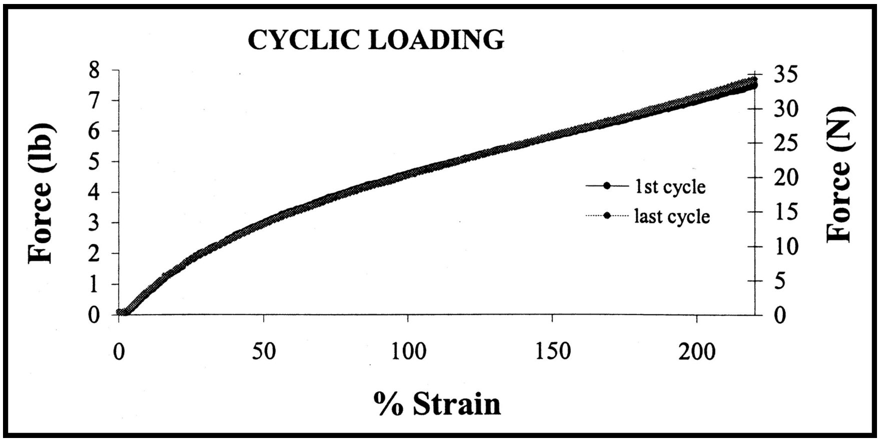

Figure 5.
Graph showing force versus percentage of strain before cyclic loading (black line) and after cyclic loading (gray line).

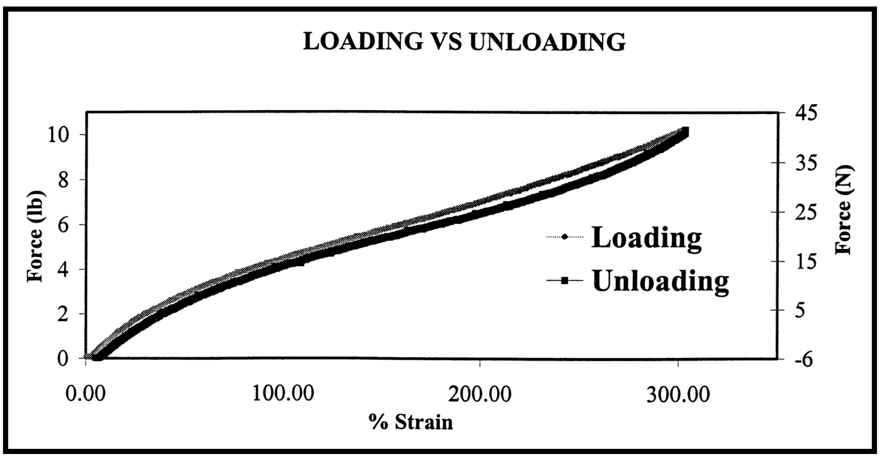

Figure 6.
Difference between the loading and unloading curves for black tubing.

percentage of strain; however, larger differences occurred at higher percentages of strain, causing the slopes to differ. The average FS curve slopes and average forces between stretched and unstretched samples at each percentage of strain (up to 225% strain) for 7.6- and 19.1-cm samples of yellow and black tubing are shown in Table 2.

Loading Rate

There were no differences between the FS curves or slopes attributable to loading rate. The average FS curve slopes and average forces attributable to loading rate at each percentage of strain (up to 300% strain) for black and blue tubing at loading rates of 5.1 and 50.8 cm/min are shown in Table 3.

Repeatability

There were no differences between the FS curves or slopes in repeated trials (Fig. 4). The average FS curve slopes and average forces between runs at each percentage of strain (up to 200% strain) for the first and second trials of 7.6-cm samples of yellow and red tubing are shown in Table 4.

Cyclic Loading

There were no differences in FS curves or slopes between the first and last cycles of loading (Fig. 5). The average FS curve slopes attributable to cyclic loading at each percent strain (up to 250% strain) for green tubing before and after cycling over 5,000 cycles were 0.05 and 0.05, respectively. The average difference in force between the first and last cycles was -0.22 ± 0.31 (–1.11 to 0.27) N.

Loading Versus Unloading

There were differences in FS curves and slopes and forces attributable to loading direction. Figure 6 shows an example of loading and unloading curves. The unloading curve displays a lower force for the same percentage of strain. The average FS curve slopes and average forces attributable to loading direction at each percentage of strain (up to 300% strain) for blue, green, black, and silver tubing during loading and unloading are shown in Table 5.

Cumulative Resistance Chart

Figure 7 displays the cumulative FS results for each of the 6 colors of tubing tested. The material displays a nonlinear behavior in the initial stretching phase (typical of elastomeric materials) and a linear behavior after 50% elongation.

Discussion

We studied the material properties of Thera-Band Tubing. The results are presented as a cumulative resistance chart in Figure 7, which displays the cumulative FS results for each of the 6 colors of tubing tested. This chart shows information that can provide knowledge about the forces generated in exercises when Thera-Band Tubing is used.

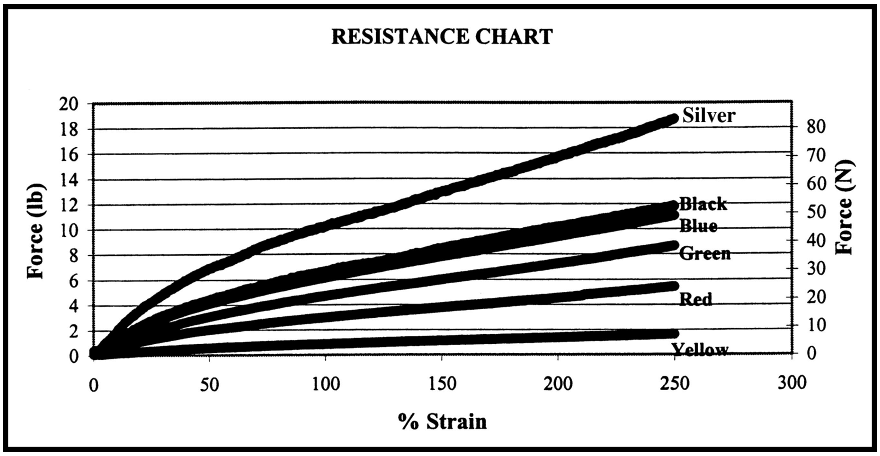

Figure 7.
Chart showing the force generated at each percentage of strain for each color of Thera-Band Tubing (copyright applied for 2000).

Length Effect

There were no differences in resistance attributable to the length of the tubing. Similar behavior for different lengths of specimens is certainly expected, and these findings confirm this expectation for the tubing used in this study. These findings should adequately represent the behavior of longer lengths of tubing commonly used in exercises.

Prestretching Effect

There were differences in the force-generating potential when the material was used new, directly out of the box. Prestretching as little as 20 times appeared to stabilize the material so that it exhibited consistent force-generating properties. Thus, prestretching will probably occur in clinics during the demonstration to the patient of how to perform exercises.

Repeatability and Cyclic Loading

The force-generating potential of the material was repeatable over at least 5,700 cycles. The maximum difference in force before and after prestretching was 0.98 N. This finding implies that during exercise, there is less than a 1.1-N difference in the force-generating potential of the tubing. Ten repetitions each of 4 different exercises, 3 times per day for 6 weeks, with the same piece of tubing would mean that the material would go through 5,040 cycles. This information implies that one patient could use the same new piece of tubing for at least 6 weeks before potentially needing another piece of tubing.

Loading Rate

There was no effect attributable to the loading rate. The tubing was tested at relatively slow stretching rates of 5.1 and 50.8 cm/min. These rates correspond to 67%/min and 667%/min, respectively. The higher rate also converts to about 11%/s, which would represent stretching a 30.5-cm-long piece of tubing an additional 30.5 cm in about 9 seconds (100% strain in 9 seconds). Furthermore, there were no differences in results for a 10-fold increase in loading rate. These results cannot be directly extrapolated to higher loading rates, but it is nevertheless noteworthy that the results at the lower end of what we believe is the clinically relevant range of lengths were not different from those for quasi-static loading.

Table 5.
Slope and Force Values for the Loading and Unloading Portions of the Curve

Color	Load/ Unload	FS[a]	Average Force Difference (N)
Silver	L	0.27	9.3±1.87 (0.31 to 12.0)
	U	0.22	
Black	L	0.18	4.23±0.8 (2.23 to 5.34)
	U	0.13	
Green	L	0.13	1.25±0.67 (−1.16 to 2.0)
	U	0.11	
Blue	L	0.13	2.72±2.05 (−4.27 to 4.18)
	U	0.13	

[a] FS=force-versus-% strain slope.

Loading Versus Unloading

There were differences in the force-generating potential of the tubing when the material was being actively stretched (lengthened) and unstretched (allowed to go back to its original length). The force-generating potential was higher during loading than during unloading: 9.3 N for silver, 4.23 N for black, 1.25 N for green, and

2.72 N for blue tubing. During exercise protocols, this finding may mean that more force is generated during the concentric portion of the exercise than during the eccentric portion. To accommodate for the lower unloading force-generating potential of the tubing, a therapist may need to increase the tension either by using a different color or stretching to a longer length during eccentric exercise.

Our results are in agreement with those of previous studies, with a maximum overall force difference of 4.9 N (1.1 lb) for yellow, 16.5 N (3.7 lb) for red, 19.1 N (4.3 lb) for green, 12.9 N (2.9 lb) for blue, 20.5 N (1.6 lb) for black, and 1.9 N (1.1 lb) for silver tubing. Tafel et al[11] reported the forces required to elongate 30.5-cm (~12-in) pieces of Exertubing. Comparisons between their data and those of this study revealed force differences of 0.2 kg (0.5 lb) for yellow, 1.0 kg (2.2 lb) for red, 0.6 kg (1.3 lb) for green, 0.3 kg (0.7 lb) for blue, and 0.6 kg (1.3 lb) for black tubing at 100% strain rates. Force differences at 200% strain rates were 0.5 kg (1.1 lb) for yellow, 1.7 kg (3.7 lb) for red, 1.1 kg (2.4 lb) for green, 0.8 kg (1.8 lb) for blue, and 1.3 kg (2.9 lb) for black tubing. Hughes et al[5] reported percent band length changes for 116.8-cm (~46-in) pieces of Thera-Band Tubing. Comparisons between their data and our data indicated force differences of 3.2 N (0.7 lb) for yellow, 4.8 N (1.1 lb) for red, 6.1 N (1.4 lb) for green, 2.8 N (0.6 lb) for blue, 3.5 N (0.8 lb) for black, and 4.7 N (1.1 lb) for silver tubing at 100% strain rates. Mikesky et al[1] investigated the force-generating potential of 305-mm-long pieces of Thera-Band Tubing. Comparisons between their data and our data indicated force differences of 11.8 N (2.7 lb) for red, 19.1 N (4.3 lb) for green, 12.8 N (2.9 lb) for blue, and 20.5 N (4.6 lb) for black tubing at 100% strain rates.

Simoneau et al[12] investigated the tensile force of 20- and 40-cm lengths of yellow, black, and green Thera-Band Tubing at a rate of 108 cm/min. They tested similar lengths of material as ours (we tested 7.6- and 19.1-cm lengths) but at a faster rate (we tested at 5.1 and 50.8 cm/min). Because we found that there was an effect of prestretching on the tubing, we compared our results with those of Simoneau et al after 50 cycles of stretching. At 100% strain, they reported forces of 4.0 N for yellow, 21.1 N for green, and 32.8 N for black tubing, similar to our results of 3.8 N, 20.9 N, and 29.5 N, respectively. At 200% strain, Simoneau et al reported forces of 6.0 N for yellow, 31.8 N for green, and 46.9 N for black tubing, also similar to our results of 6.1 N, 32.2 N, and 44.8 N, respectively. These differences amount to a maximum difference in force of 2% at 100% strain and 7% at 200% strain between the 2 studies.

We did not test the effects of the age (shelf life) or of different lots of materials. Only one box (lot) of each color was ordered and was tested within 6 months of shipping. In addition, we did not test the effects of temperature or humidity on the materials. The material properties of the tubing may change when it is used outdoors or after contact with salt residues from sweat. Some people who have used this material in aerobics classes have told us that in their experience, the material becomes brittle over time and after getting wet. We did not test these scenarios.

Conclusion

On the basis of our data, we developed a cumulative resistance chart, shown in Figure 7, which displays the cumulative FS results for each of the 6 colors (resistance levels) of tubing tested. From this information, a therapist can determine which color of tubing to use to obtain a specific force level and percentage of strain (percentage of length change). For example, for an exercise in which the tubing is stretched to twice its original length at the end of the motion (100% strain, as measured on the *x* axis), there would be maximum forces of 3.78 N for yellow, 13.22 N for red, 20.87 N for green, 27.19 N for blue, 29.55 N for black, and 45.35 N for silver tubing. We believe that the information in this chart can provide therapists with knowledge about the forces generated during exercises with Thera-Band Tubing that will enable them to choose which size of tubing to use for each patient.

References

1 Mikesky AE, Topp R, Wigglesworth JK, et al. Efficacy of a home-based training program for older adults using elastic tubing. *Eur J Appl Physiol.* 1994;69:316–320.

2 Hall L, Thein B. *Therapeutic Exercise: Moving Toward Function.* Philadelphia, Pa: Lippincott Williams & Wilkins; 1999:575–625.

3 Kissner C, Colby LA. *Therapeutic Exercise: Foundations and Techniques.* 3rd ed. Philadelphia, Pa: FA Davis Co; 1990:96–97.

4 Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. *J Orthop Sports Phys Ther.* 2000;30:126–137.

5 Hughes CJ, Hurd K, Jones A, Springle S. Resistance properties of Thera-Band tubing during shoulder abduction exercise. *J Orthop Sports Phys Ther.* 1999;29:413–420.

6 Fess EE, Phillips CA. *Hand Splinting Principles and Methods.* St Louis, Mo: CV Mosby Co; 1987:163–187.

7 Hertling D Kessler RM. The shoulder and shoulder girdle. In: Hertling D, Kessler RM, eds. *Management of Common Musculoskeletal Disorders: Physical Therapy Principles and Methods.* 3rd ed. Philadelphia, Pa: Lippincott; 1996:186.

8 Brotzman SB, Brasel J. Foot and ankle rehabilitation. In: Brotzman SB, ed. *Handbook of Orthopaedic Rehabilitation.* St Louis, Mo: Mosby; 1996:268–271.

9 Schultz-Johnson K. Splinting: a problem-solving approach. In: Stanley BA, Tribuzi SM, eds. *Concepts in Hand Rehabilitation*. Philadelphia, Pa: FA Davis Co; 1992:238–271.

10 Hintermeister RA, Bey MJ, Lange GW, et al. Quantification of elastic resistance knee rehabilitation exercises. *J Orthop Sports Phys Ther*. 1998;28:40–50.

11 Tafel JA, Thacker JG, Hagemann JM, et al. Mechanical performance of Exertubing for isotonic hand exercise. *J Burn Care Rehabil*. 1987;8:333–335.

12 Simoneau GG, Bereda SM, Sobush DC, Starky AJ. Biomechanics of elastic resistance in therapeutic exercise programs. *J Orthop Sports Phys Ther*. 2001;31:16–24.