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Mechanical evaluation of the resistance of elastic bands

Avaliação mecânica da resistência de faixas elásticas

Gilmar M. Santos[1], Graziela M. S. Tavares[2], Graziela de Gasperi[2], Giseli R. Bau[3]

Abstract

Background: Elastic bands are frequently used for resistance training, however the selection of the bands to progress through the levels of elastic resistance is done in a subjective manner. This is due to the lack of quantitative data on the value of the material's resistance as a function of its tension. **Objectives:** To investigate the elastic resistance generated by each of the eight color-coded resistance levels of elastic bands, using 100% elongation, and to quantify the resistance variation from one level to the next. **Methods:** Tensile testing was performed in compliance with ASTM Standard D412-06a. The sample consisted of 80 die-cut test specimens (Die C) taken from the eight color-coded resistance levels. The sample was submitted to tensile testing in the universal testing machine EMIC DL-3000. Each of the tension cycles was performed at a speed of 500mm/sec. Statistical analysis was done using one-way ANOVA, with a significance level of $p<0.05$. **Results:** The sample showed a significant difference between all levels of resistance, except for the yellow (thin) and red (medium) elastic bands. The variation in resistance between the bands shows that the gold (max) band offers 5.13 times more resistance than the tan (extra thin) band, and that the greatest variation in progressive resistance is between the black and the silver bands. In addition, Young's modulus showed linear behavior between the different colors. **Conclusions:** The results showed that the elastic resistance and stiffness of the material exhibits a linear and progressive variation. In addition, the data suggested the possibility of progressing from the tan band to the red band, skipping the yellow band, when prescribing resistance exercises.

Key words: elastic bands; elastic resistance; tensile testing.

Resumo

Contextualização: As faixas elásticas são frequentemente utilizadas em programas de treinamento resistivo, entretanto a seleção da progressão entre os níveis de resistência elástica é feita de maneira subjetiva em virtude da deficiência de dados quantitativos que expressem o valor da resistência em função da tração do material. **Objetivos:** Investigar a resistência elástica gerada em cada um dos oito níveis de resistências das faixas elásticas em 100% de alongamento e quantificar a variação existente de um nível para outro. **Métodos:** A amostra foi constituída de 80 corpos de prova, retirados dos oito níveis de resistência. O ensaio de tração nos corpos de prova modelo C foi realizado conforme a norma técnica ASTM D 412-06[a] pela máquina universal de ensaios DL EMIC 3000. Cada ciclo de tração foi realizado na velocidade de 500 mm/seg. Para a análise estatística, utilizou-se o teste Anova one-way com nível de significância de $\rho<0,05$. **Resultados:** A amostra apresentou diferença significativa da resistência elástica no espectro de níveis avaliados, exceto entre as resistências suaves (amarelo) e médias (vermelho). A análise da variação da resistência entre as faixas mostra que a dourada (máximo) oferece 5,13 vezes mais resistência que a branca (extrasuave), e a maior variação na progressão encontra-se entre as faixas preta e cinza. Além disso, o módulo de Young apresentou comportamento linear entre as diferentes cores. **Conclusões:** Os resultados mostraram que a variação da resistência elástica e da rigidez do material são progressivas entre os diferentes níveis. Além disso, os dados sugerem a possibilidade de progressão da faixa branca para a vermelha, eliminando a amarela na prescrição de exercícios de fortalecimento.

Palavras-chave: faixas elásticas; resistência elástica; ensaio de tração.

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[1] Department of Physical Therapy, Universidade do Estado de Santa Catarina (UDESC), Florianópolis (SC), Brazil
[2] Graduate Program in Human Movement Sciences, UDESC
[3] Physical Therapy Course, UDESC
Correspondence to: Gilmar Moraes Santos, Rua Professor Bayer Filho, 125, Coqueiros, CEP 88080-300, Florianópolis (SC), Brazil, e-mail: d2gms@udesc.br

Introduction

Resistive elastic materials, such as bands and tubes, are low-cost and highly versatile tools often used in therapeutic exercise programs[1-3]. They are also convenient for patients to train at home using a variety of movement, including eccentric and concentric contractions[4]. According to Pereira and Gomes[5], training against resistance is an important tool in the prevention and maintenance of quality of life regarding health, and recommendations suggest that it should be part of exercise programs for young adults and the elderly.

To improve the prescription of muscle reeducation programs (dynamic strength training), physical therapists must learn the correct use of elastic bands for therapeutic purposes. Elastic bands (Thera-Band™) emerged in rehabilitation centers of the United States in the 1980s[6]. In Brazil, latex bands made from polymerized synthetic rubber, known chemically as styrene-butadiene, are used on a large-scale[7]. However, the elastic bands produced by the Hygenic Corporation (Thera-Band™) contain natural rubber latex that provides better elasticity and lower susceptibility to rupture[8]. Elastic band and tube manufacturers provide a range of products with different resistance levels usually distinguished by color. In theory, this spectrum makes it possible to offer to the patient the elastic band that best corresponds to the resistance level that is appropriate for his/her rehabilitation process, i.e. the force needed to elongate the material.

Hostler et al.[9] analyzed the effectiveness of a short-term training program using elastic resistance in young adults and found skeletal muscle adaptations, such as: an increase in the percentage of type IIab fibers for both men and women; a decrease in the percentage of type IIb fibers in men; and minor changes in fiber type composition (IIb → IIab), fiber size and capillarization. However, one disadvantage of using elastic resistance is the progressively greater force required with the elongation of the material. Near the end of the range of motion, an individual may not be able to perform the movement as desired, due to the weakness of the muscles undergoing rehabilitation or because the muscle is in a shortened position at a point where the resistance of the material is greater[4].

It is argued that the misuse of the material can be harmful, because the use of force, torque or too much pressure may cause inflammation, keloid scarring or even deformities[4]. Another disadvantage of elastic resistance lies in the fact that not all elastic materials provide similar tension[4]. Therefore, it is essential to understand the mechanical properties of the material, which would imply the need to define the proportion between the different colors for the implementation of a suitable clinical treatment[4], allowing the physical therapist to have greater control over the load offered to the patient.

Some studies[1,2,10,11] have been conducted on the properties of elastic bands. These studies had different objectives, such as: establishing the stress-strain relationship of 12 samples of elastic bands[1]; investigating the relationship between force and percentage of change in length for six different colors of elastic tubes, by direct measurement of force and motion analysis during shoulder abduction exercise[2]; measuring the resistance as a function of elongation in seven colors of elastic bands[10], and quantifying the resistance (force as a function of elongation) of six colors of elastic bands, allowing the construction of an index for color selection[11]. However, none of these studies[1,4,6,10] followed the technical standards necessary to carry out the tensile tests under controlled conditions (temperature, humidity, etc.) and thus determine the curves which show the correlation between the exerted force and the deformation caused in the material.

It is argued that the search for objective data may better evaluate and direct the client's progress, thus allowing evidence-based physical therapy treatment. Additionally, the previously cited authors[1,4,6,10] suggest further research to study the biomechanics of the elastic material in mechanically controlled trials in order to determine the real resistance change as a function of elongation. Therefore, the present study aimed to investigate the elastic resistance, i.e. force as a function of the elongation generated in each of the eight color-coded resistance levels of the elastic bands at 100% elongation and quantify the resistance change between each level.

Methods

This experimental study[12] was conducted at the Instrumentation Laboratory (LABIN) of the Health and Sports Sciences Center (CEFID) during April and May 2008. The sample consisted of 80 die-cut test specimens, taken from the eight resistance levels represented, in order of increasing tensile resistance, by the colors tan (extra thin), yellow (thin), red (medium), green (heavy), blue (extra heavy), black (especially heavy), silver (super heavy) and gold color (max). Ten samples were taken from each resistance level.

Instruments

For the tensile test, we used the microprocessor-based electromechanical universal testing machine EMIC DL-3000 with force and displacement data acquisition through Virmaq (version 3.04) and Tesc (version 3.04) software[13]. The load cell used in this trial was the PLA model (Líder Balanças-SP) on a rigid base with a nominal capacity of 20 kgf.

The load cell was placed between the metal clip, used to attach the elastic material to the rigid base, and the rigid base itself, used to measure the tension produced by the elastic material. Data were collected at a sampling frequency of 30 Hz by 12-bit A/O system and then stored in a computer.

In order to obtain the data proposed by this study, a tensile test was performed in compliance with ASTM Standard D412-06a[14]. The die-cut test specimens were taken from the eight color-coded resistance levels commercialized by MERCUR SA®, the Brazilian representative of Thera-Band™. To prepare the die-cut test specimens, a model AC5 09 cutting die, equivalent to Die C as described in the standard, was used. The choice of elastic bands was simply based on the intention to test a range that crossed all levels of resistance that can be offered to patients.

The die-cut test specimens were standardized and measured for length, width and thickness with a Mitutoyo Digital Caliper®. The mean of the 80 samples was 115 mm in length, with 20 mm required at each end to set the band safely in the metal clamps. The width ($\bar{x}$=6.5 mm ± 0.11) and thickness ($\bar{x}$=0.26 mm ± 0.18) of the die-cut test specimens were also measured. The actual test area was standardized as 75 mm. Three points were standardized on the base, through measurements and calculation of the corresponding mean, to measure the width and thickness of the area to be deformed during the test for each specimen.

The elongation speed was set at 500 mm/min, which corresponds to an exercise carried out at a very low speed, simulating the optimal use of the elastic band in clinical practice[1]. Each die-cut test specimens was elongated once for 5 seconds on average. From the elongation, it was possible to determine the 80 curves of force versus percentage of deformation of the material in a 100% elongation, conventionally known as the maximum apparent deformation performed by a patient in clinical use.

Data collection

The die-cut test specimens were submitted to controlled temperature and humidity, according to ASTM Standard D412-06a[14] for at least three hours prior to and throughout the trials. To conduct the trial, each specimen was attached to the test apparatus with clamps, so that the material was at resting length. During testing, each die-cut test specimen was subjected to a cycle of elongations until the material ruptured or became detached from the clamps or until elongation without rupture or detachment followed by the return to the starting position.

The tension of the elastic material (resistance to traction) was measured throughout the trial. The variation in elastic resistance between the different levels (colors) of the material was also measured. In this study, we chose to present the results of the resistance in Newtons, in a 100% deformation. The choice of this percentage of deformation was based on a test with an individual simulating shoulder and knee joint movements with elastic band resistance. The tests showed that, in the movements, the individual did not exceed 100% deformation.

Treatment of data

For statistical analysis between the different levels of resistance at 100% elongation, one-way ANOVA and post-hoc Tukey tests were used. The significance level was set at $p<0.05$.

Results

The results of this study (Table 1) showed a statistically significant difference between the levels of resistance, except between the levels represented by the yellow and red bands ($p=0.107$). Table 1 shows the mean force values and their standard deviations, at 100% elongation, for each resistance level of the elastic bands. The forces are presented in Newtons (N) and represent progressive elastic resistance from the tan to the gold band. Young's modulus showed progressive, linear behavior in the stiffness of the material between the different colors (Table 2). This table also shows the Pearson's product-moment correlation (r) and coefficient of determination (r^2) for the color-coded resistance levels.

In the comparison of stress-elongation curves between the eight color-coded resistance levels (Figure 1), there is a lack of overlap between them and a progressive behavior in the force necessary to deform each band in the resistance levels offered by the manufacturer.

Figure 2 shows the percentage change in elastic resistance in the range of resistance levels tested at 100% elongation. The results showed that the gold band (12.4 N) offers 5.13 times more resistance than the tan band (2.0 N).

Discussion

The results showed that the force-deformation and stress-elongation relationship of the elastic bands commonly used in therapeutic exercise showed a strong linear relationship up to 100% deformation, i.e. the increase in length corresponded to a progressive increase in the elastic resistance and stiffness of the material in the color sequence: tan, yellow, red, green, blue, black, silver and gold. Furthermore, the results showed a

Table 1. Mean and standard deviation of elastic resistance for color-coded resistance levels.

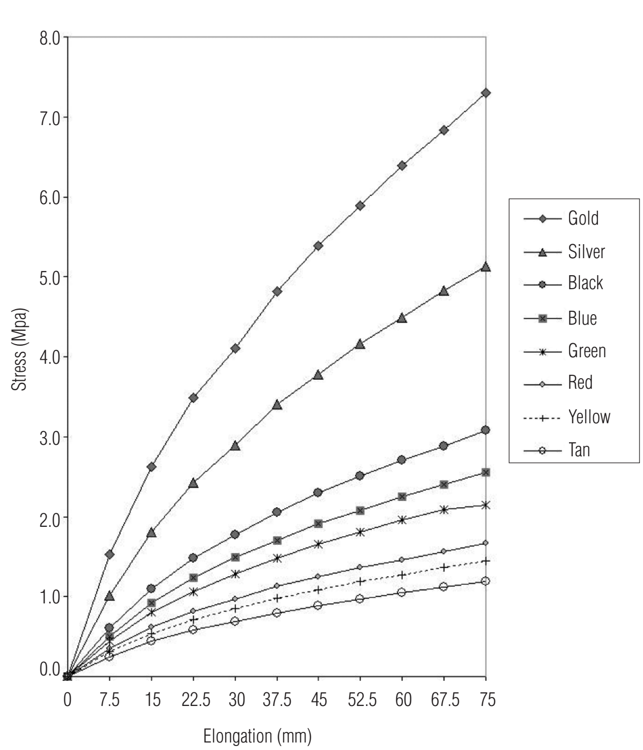
Colors	n	Elastic Resistance	ρ
Gold	10	12.4 N (±0.51)	0.000*
Silver	10	8.6 N (±0.39)	0.000*
Black	10	5.2 N (±0.22)	0.000*
Green	10	4.3 N (±0.16)	0.000*
Blue	10	3.7 N (±0.09)	0.000*
Red	10	2.7 N (±0.06)	0.107
Yellow	10	2.4 N (±0.16)	0.107
Tan	10	2.0 N (±0.08)	0.000*

N=Newton; n=sample; Significance level=p<0.05. * statistically significant differences between color-coded levels of elastic resistance.

Table 2. Mean and standard deviation of Young's Modulus, Pearson's product-moment correlation and coefficient of determination for color-coded resistance levels.

Colors	Young's Modulus (MPa)	r	r^2
Gold	2.75 (±0.21)	0.98	0.96
Silver	2.43 (±0.11)	0.98	0.96
Black	2.22 (±0.12)	0.97	0.95
Green	2.47 (±0.09)	0.97	0.95
Blue	2.31 (±0.09)	0.97	0.97
Red	2.28 (±0.06)	0.97	0.95
Yellow	2.56 (±0.11)	0.97	0.94
Tan	2.00 (±0.69)	0.97	0.95
Mean	2.38 (± 0.23)	0.97	0.95

MPa=megaPascal.



MPa=megapascal; mm=millimeters.

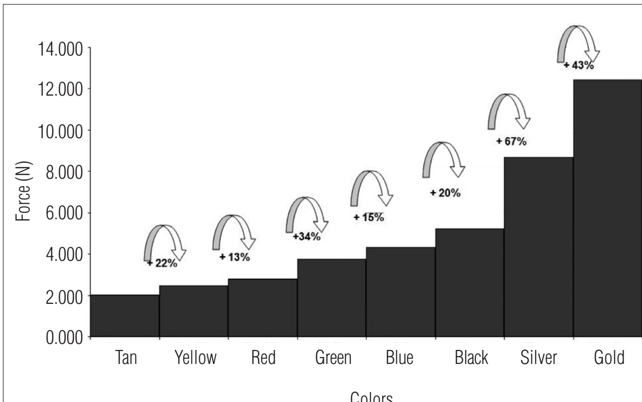
Figure 1. Stress curve up to 100% elongation for color-coded resistance levels.

mean value of r^2 equal to 0.95, in agreement with Hughes et al.[2] and Page, Labbe and Topp[10] who also found a linear force-deformation relationship with mean values of r^2 of 0.93 and 0.97, respectively. In this linear behavior, there was a 53.8% variation from the least resistant band (tan) to the most resistant band (gold).

These results showed a variable slope of the curve in the stress-elongation relationship for each color of elastic band. For each change in elastic band, there is a non-uniform change in recoil force. At the same level of deformation, there is a 20 to 67% change in the level of recoil force between successive elastic bands. Thus, the smallest increment in force, i.e. the least progression of difficulty, occurs between the yellow and red bands, while the greatest increase in force, i.e. the greatest difficulty in progression occurs between the black and silver elastic bands.

The percentage difference of 13.1% in elastic resistance between the yellow and red elastic bands was not significant, suggesting that, in clinical practice, the progression between the bands can be made directly from tan to red because of this small increase in resistance. Additionally, the data show that extra care must be taken when the physical therapist progresses from the black to the silver band, because this progression showed the highest value (67%) of change in elastic resistance.

Brien et al.[15] and Mikesky et al.[3] were the first to mention a formal method or a mechanical procedure for determining elastic resistance as a function of elongation before starting a training program. However, the studies[1,4,6,10] on the properties of elastic bands and tubes were performed in clinical settings, which hinders a more accurate comparison to the data obtained in the present trial. Despite this difficulty, it must be highlighted that the trial was based on international standards for tensile trials in which control criteria must be followed to obtain die-cut test specimens of standardized shapes and



N=Newton.

Figure 2. Percentage change in elastic resistance for color-coded resistance levels

sizes so that the results can be compared or, if necessary, reproduced.

The Hygenic Corporation (Thera-Band™)[8], through the manufacturer's manual for elastic bands and tubes, provides a range of forces required to elongate the material at different percentages. These data come from a study by Page, Labbe and Topp[10] that measured resistance as a function of elongation by fixing one end of the elastic band to an exercise handle and the other end to a plastic clip attached to a strain gauge. The gauge quantified the force generated to the nearest 0.5 kg, according to a protocol with samples of the seven colors (the tan band was not tested) cut into different lengths. Each elastic band was manually elongated at a rate of 1 inch/second, with elongations of 25% to 250% recorded from the first length of the sample. The authors' conclusion indicates that the elastic bands provide a consistent and predictable increase in force as a function of the elongation at all levels of resistance, as found in the present study.

However, it was not possible to compare the present data with data supplied by the manufacturer because the study by Page et al.[10] did not mention any technical standard and because the instruments and especially the dimensions of the die-cut test specimens were quite distinct. The main limitation is due to the width of the samples, ranging from 6.5 mm on average in the present study to 100 mm in the referred study[10], a difference that directly influence the force needed to elongate the material. The difference in length does not affect the comparison of the forces because the elongation percentage is the same[16].

Based on the variations of resistance between the colors of elastic bands in the present trial, it is possible to quantify the overload offered to the patient when progressing from one resistance level to the next. It is also possible to establish more appropriate level transitions, offering a progression of resistance according to the need and purpose of treatment, thus providing safety, efficiency and objectivity when choosing an elastic resistance treatment program. Moreover, through tensile trials that measure the properties of elastic materials, elastic resistance exercise protocols may be validated.

Conclusions

After the tensile trial, the results showed that the elastic bands have a progressive and linear behavior in elastic resistance and stiffness of the material between the different colors at 100% elongation, corroborating that the order of colors (tan, yellow, red, blue, green, black, silver and gold) indicates least to greatest resistance. The analysis of elastic resistance between bands showed that the greatest variation occurs between the black and silver bands, suggesting that the physical therapist must take particular care when deciding to transition from one to the other. Furthermore, the results suggest that it is possible to advance from the tan to the red band, eliminating the need for the yellow band, when prescribing a strengthening program. Finally, the results suggest that the transition in elastic resistance between tan, yellow, red, blue, green and black bands can be safely used during physical therapy treatment.

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