211 - RESISTANCE OF ELASTIC TUBES EMPLOYED IN REHABILITATION AND SPORTS TRAINING PROTOCOLS

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INTRODUCTION

Currently, a great amount of exercises has been prescribed in order to increase the amplitude of articulate movements, force, power and muscular endurance and still, the improvement of cardio-respiratory function (located resistance). The external overload presented in these exercises can be characterized as constant or variable during the concentric-eccentric range of motion (ROM) (Kreighbaum & Barthels, 1999).

The variable resistance to the effort can be produced by means of the use of materials with elastic properties capable to store elastic potential energy, such as metal springs, tubes and elastic bands (Hughes et al., 1999). These materials have as characteristic to offer higher resistance to the end of the ROM (Hintersmeister et al., 1998a).

Tubes and elastic bands are widely used due to its versatility, viability and nonreliance on gravity, differently from the resistance training with fixed load dependent on the gravity (Sacharuck et al., 2005; Ribeiro et al., 2005).

Elastics Thera-band®, Rubber-band® and Cando® of natural rubber and national latex tubes, available in the market, provide a considerable resistance specter reliance on the initial thickness and length of the elastic material (Simoneau et al., 2001). For instance, the higher the thickness the higher the resistance offered for an initial fixed length and the lower the initial length the higher the resistance imposed to the exercise and the higher the strength needed to strain it to a same target length (Simoneau et al., 2001).

The elastic resistance is widely employed in rehabilitation protocols aiming the gain of the ROM in different corporal segments and in sports training, as overload method of variable resistance (Benatti, 2005).

The exercises with variable resistance have been classified as isokinetics when the velocity is constant during the ROM and when compared with the constant load exercise, the resistive torque curve is similar to the isotonic exercise (Hughes et al., 1999).

Differently from the resistance exercises of fixed load, quite standardized in the literature concerning to the protocols and the effort intensity, the resistance exercises of variable overload need more researches, for, although the increased number of studies, it is not noticed a consent related to the mechanical characterization of the elastic resistance and tubes and elastic bands standardization, being used, therefore, in an uncertain way based on the subjective perception of the performer's effort as in the rehabilitation context as in the sports training (Hintersmeister et al. 1998b, Benatti, 2005).

The determination of the resistance offered to the effort by means of tubes and elastic bands has been carried through two ways: (1) Qualitative, based on the subjective perception of individual effort (Treiber et al., 1998); and (2) Quantitative, by means of the determination of the resistance in an alternative manner from the material strain and the objects of known mass in a static and progressive way according to Loss et al. (2002), or captivating devices of kinetics data such as force transducers and mechanical testing machines.

Thus, the optimal use of elastic materials for exercises depends on the quantitative understanding of the physical properties of the material in such way that these information can assist in the extent of description, monitoring and analysis of rehabilitation and sports training protocols (Azevedo, 2003).

One of the main properties of the elastic material is their elastic resistance. With the loading cyclic application the elastic tubes lose their capacity to respond, with the same resistance, to the same amount of stretching (Simoneau et al., 2001).

Thereby, the purpose of this study was to determine the resistance offered by Thera-band - Silver elastic tubes of American production widely employed in clinical practice and national Auriflex 204 latex tubes of less cost. The analysis assessed the relationship between the strain (%) in function of applied traction force.

MATERIALS AND METHODS

It has been selected national Auriflex 204 latex tubes found in the market and Thera-band -Silver of American production (Fig.1). Each sample was composed by 3 bodies test with 60mm useful length (Fig. 2). The determination of bodies test dimensions have been carried through using a caliper of Stainless Hardened 508045 brand with a 10 cm and nonius 0,05 mm metallic graduated scale.

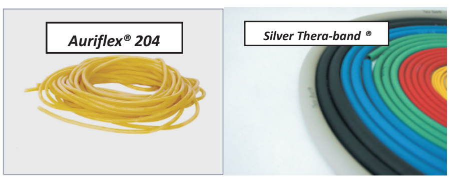

Figure 1 - Elastic Tubes.

Figure 2 - Body test.

The analysis of elastic resistance of elastic tubes has been done using a MTS 810® (Material Test System Corporation, Minneapolis, Minesota, USA) mechanical testing machine, of 250 KN maximum capacity, from the Mechanical Projects Laboratory "Prof. Henner Alberto Gomide" of the School of Mechanical Engineering (FEMEC/UFU) as shown in figure 3.

It has been projected and built an attachment device of elastic tubes. The device can attach until three bodies test for the resistance assessment. The attachment is done through a plug adapted to base holes and tensioned by screws.

Carbon steel pins were adapted to the internal diameter of the bodies test, in the two extremities, in order to increase the rigidity and to facilitate the attachment of elastic tubes. Figure 4 shows the projected support as well as the plugs and the metallic pins.

The mechanical characterization followed similar parameters from those utilized in studies of Azevedo (2003) and Benatti (2005). The bodies test were submitted to an axial traction test corresponded to 10 stretching cycles, however, achieving a 166.66% maximum strain from the initial length, at a 500 mm/min loading rate. The force and displacement data were acquired at a 240 points rate for loading-unloading cycle.

Figure 3 - LPM's Universal Testing Machine (MTS 810®).

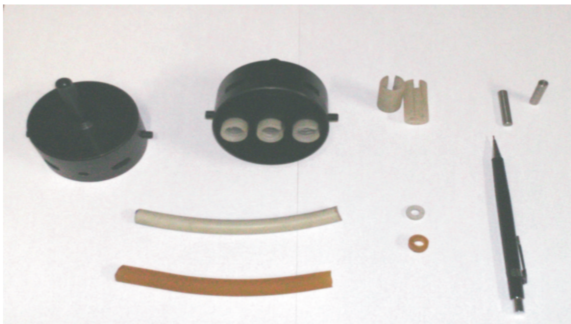

Figure 4 - Attachment device, plugs and pins.

Figure 5 - Axial traction test.

Figure 5 shows the latex tube attached to the mechanical testing machine during the cycling accomplishment. It has been used the MPT (Multi Purpose Tortwore) device from the MTS for the treatment and acquisition of the force and displacement signs. It has been obtained from tests medium values for signs of force, displacement and tension of the bodies test of Thera-band and Auriflex tubes in 10 stretching cycles and the interpolation equations (curves adjust) employing the statistic device OriginPro 7.5®.

RESULTS

Table 1 shows the cross-sectional area in different studies for national elastic tubes. the cross-sectional area of tubes (1) Auriflex® 204 and (2) Thera-band silver are:

(D) External diameter = 12 mm;

(d) Internal diameter = 6 mm;

$$A_{\text{Auriflex 204}} = (\pi/4)(D^2 - d^2) = 84.823\,mm^2 \quad (1)$$

(D)External diameter = 11.5 mm;

(d) Internal diameter = 5.5 mm;

$$A_{\text{Theraband}} = (\pi/4)(D^2 - d^2) = 71.275\,mm^2 \quad (2)$$

The normal stress (σ) of approximate traction for the elastic tubes can be determined for:

$$\sigma = F/A \quad (3)$$

In equation (3), F is the applied traction force and A the area of the transverse section. The longitudinal strain (ε) is determined for:

$$\varepsilon = \Delta l / l_0 \qquad (4)$$

In equation (4), Δl is the length variation and l0 the initial length (60 mm). Table 2 shows the medium force (N) at a 50%, 100% and 166% strain, obtained by means of elastic material cycling. Table 3 shows the interpolation equations for the assessed bodies test. Figure 6 shows the relationship stress versus strain for the analyzed elastic tubes applying the equations (3) and (4).

Table 1 - Cross-sectional area of national latex tubes (mm2).

Authors	***Elastic Tubes***	***Area (mm^2)***
Benatti (2005); Azevedo (2003) Benatti *et al.* (2003)	Lengruber 204	84.83
***	Auriflex 204	84.823

*** Current study.

Table 2 - Relationship Force (N) versus (%) strain.

Elastic Tubes	***50%***	***100%***	***166%***
Auriflex® - 204	22.5 ± 1.99 N	41.66 ± 1.96 N	54.68 ± 1.88 N
Thera-band® - silver	24.47 ± 2.5 N	45.62 ± 2.31 N	61.67 ± 1.91 N

Table 3 – Interpolation equations.

Specification	***Equations***
Auriflex® - 204	$F = -3.66462 + 0.57945\varepsilon - 0.00109\,\varepsilon^2 - 1.7264\,\varepsilon^3$
Theraband® - silver	$F = -4.35245 + 0.64685\varepsilon - 0.00142\varepsilon^2 - 5.094417\,\varepsilon^3$

F= Force (N); ε = strain (%).

Table 4 – Relationship Force (N) versus % Strain.

Authors	***Thera-band®***	***Lengruber®***
Azevedo (2003)	--------------	204 (40N; 300%)
Benatti (2005)	Blue (32.34N; 300%), Red (55.47N; 300%)	200 (17.15N; 300%), 202 (46.94N, 300%), 204 (62.72N; 300%)
Benatti *et al.* (2003)	Blue (33.32N; 300%), Red (55.47N; 300%)	200 (17.52N; 300%), 202 (47.04N; 300%)
Hughes *et al.* (1999)	Yellow (27.63N; 300%), Red (42.07N; 300%), Blue (62.42N; 300%), Green (69.92N; 300%), Black (79.38N; 300%) e Silver (118.19N; 300%)	------------
Simoneau *et al*. (2001)	Yellow (4.0N; 100 %), (6.0N; 200%), Green (21.1N; 100%), (31.8N; 200%), Black (32.8N; 100%) (46.9N; 200%)	------------
Patterson *et al.* (2001)	Yellow (3.78N; 100%), Red (13.22N; 100%), Green (20.87N, 100%), Blue (27.19N, 100%), Black (29.55N; 100%) e Silver (45.35N; 100%)	-------------

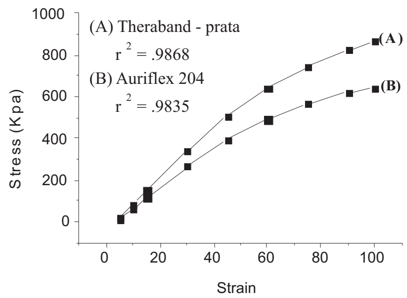

Figure 6 - Relationship stress versus strain for the elastic tubes Auriflex 204 (A) and Thera-band silver (B).

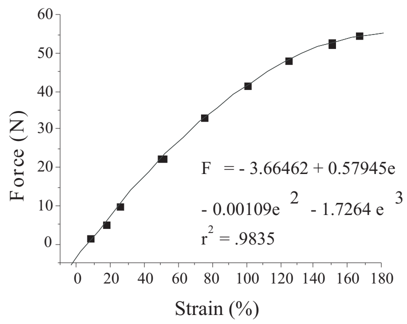

Figure 7 - Average curve of force (N) versus (%) strain (Auriflex 204).

Figures 7 and 8, respectively, show the medium values of traction force in function of strain (%) for Auriflex 204 and

Thera-band silver tubes.

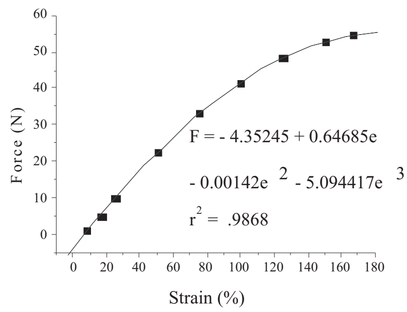

Figure 8 - Average curve of Force (N) versus (%) strain (Thera-band silver).

DISCUSSION

The elastic resistance is currently employed in rehabilitation and sports training areas due to its versatility, economic viability and nonreliance on gravity, in order to offer resistance to movement, constituting itself a strength training method.

However, few researches have been carried out on the characterization of national elastic tubes properties. It has not been found in this research any study which have assessed the properties of Auriflex ® 204 tubes neither an initiative of standardization in national elastic tubes production.

With the objective of characterizing the mechanical behavior of quadriceps muscle, when submitted to knee extension exercises with elastic overload, Azevedo (2003) quantified the elastic resistance offered by three elastic tubes (200, 202, 204) of Lengruber® brand in a mechanical testing machine (EMIC) at 300%, which it is believed to be the operational limit of the elastic tubes and even its maximum tension of rupture.

Using the same mechanical testing machine Benatti et al. (2003) and Benatti (2005) analyzed in different studies the properties of Thera-band® elastic tubes (5 red and blue bodies test) and Lengruber® national latex tubes (200, 202, 204) for values of maximum tension (300%) and hysteresis.

National latex tubes are made of polymerized synthetic rubber (butadiene-styrene) and are classified according to internal and external diameters of tubes and by the resistance offered to stretching. However, despite it is noticed the standardization in the extent of cross-sectional area (table 1), the resistance provided by elastic tubes used in this study and Lengruber® 204 tubes reported in the studies of Azevedo (2003), Benatti et al. (2003) and Benatti (2005) presented differences.

The maximum force obtained (table 2) are higher than force reported by Azevedo (2003), Benatti et al. (2003) and Benatti (2005) (see table 4), despite the cross-sectional area of the tubes used in the experiments being the same to the tubes reported by the authors (table 1). Besides, elastic tubes are constituted of the same material (butadiene-styrene). These differences can be attributed to the methods and polymers employed in its production, since they are made by different industries.

The displacement rate adopted in this study was of 500 mm/min, the same adopted in the studies of Azevedo (2003) and Benatti (2005), differently from the 51 mm/min and 508 mm/min tested by Patterson et al. (2001) with intention of verifying possible differences of force at different loading rates.

Simoneau et al. (2001) in a study on elastic material fatigue used a greater loading rate (1008 mm/min) simulating the angular velocity of the range of motion in which are carried out rehabilitation exercises with yellow, black and green Thera-band tubes and elastic bands at 100% and 200% material strain. It was verified differences of maximum force from 2% to 100% strain and 7% to 200% strain of the initial length for the study of Patterson et al. (2001).

In all cited studies except for Simoneau et al. (2001), the elastic material was submitted to a 300% maximum strain of its initial length in the strip that the product maintains its mechanical properties.

However, in this study, due to the limitation of the cursor of the mechanical testing machine, the maximum length adopted for characterization of elastic tubes was of 166.66% from the initial length.

Despite the intense use of resistance as an overloading method, few studies have been carried out on the study of the relationship force versus strain. Table 4 shows data on the relationship force versus strain of different elastic materials utilized as source of dynamic progress resistance.

Hughes et al. (1999), studied elastic tubes properties during shoulder abduction exercises. They investigated the relationship of Thera-band® elastic tubes in their different thickness (6 colours – yellow, red, blue, green, black and silver) and the resistive torque in different effort degrees (30º, 60º, 90º, 120º, 150º) generated by each tube. For that, they utilized a force transducer attached to a wooden platform in order to limit extraneous movements. In this study, it was found differences of tension from 25.41% to 50% strain, 5.63% to 100% and 16.24% to 166% for obtained data, as shown in table 2 of this study and table 4 referring to studies of other authors.

Differences found can be originated from the linear adjust utilized by Hughes et al. (1999), in detriment of the polynomial adjust adopted in this study as well as the type of material (polymer) employed in American Thera-band® production, not mentioned in its study.

Patterson et al. (2001) described the material properties of Thera-band® elastic tubes. In his study it was found significant differences to the potential of resistance generation only for the pre-stretching and loading-unloading cycle. Although, in relation to cyclic loading and repeatedly use of elastics the inferences are valid only for 5700 stretching cycles.

Comparing data obtained with the study of Patterson et al. (2001), utilized as reference pattern by Thera-band manufacturer, this study's findings are similar to 50%, 100% and 166% strain, presenting higher force values of 3.53N, 0.23N and 1.33N, respectively.

Elastic resistance has been used as overload method in a growing specter of activities related to injuries preventions, rehabilitation in the sub-acute stage of skeletal muscle, cardiac rehabilitation (Pezzulo et al., 1995, Page et al., 1993, Vanbiervliet et al., 2003), in sports training, as strength training method (pure concentric, eccentric, plyometric), action-reaction speed, speed resistance in a great variety of sports movements (Hintersmeister et al., 1998b, Vidigal, 2002, Voight et al., 1995, Weineck, 2003).

However, limiting factors for choice and quantification of elastic overload to the effort have not carried out central place in the discussion, in way to permit effort protocols standardization during its using. Among the limiting factors, it can be mentioned the relationship force versus strain and type of material related to the material's initial length, width and thickness. The understanding of these factors is fundamentally important to the effort's evaluation and prescription.

Basing on data obtained by means of the equations informed in table 3, it is possible to establish the resistance offered by elastic tubes and even the replacement of Thera-band®-silver tubes for Auriflex® 204 tubes of more accessible cost based upon the understanding of the relationship force versus strain. For instance, a Thera-band®-silver tube of 60 cm initial length strained to 100% offers a resistance of approximately 45.5N and an Auriflex® 204 with 51.34 cm initial length when stretched to a strain of approximately 114%, offers the same 45.5N final resistance.

The resistance offered by elastic tubes during the effort after successive stretchings loses the capacity of generate the same 45.5N of resistance. Nevertheless, knowing the process of material fatigue it is possible to use a correction factor for the stretching response. For instance, hypothetically, knowing the perceptual of strain and the approximate quantity of stretching employed in an established protocol, it is referred a lost of 8% for a 60cm tube strained to 100% from the initial length and an approximate quantity of 6000 loading-unloading cycles.

On the other hand, an important factor on the elastic overload progression is the standardization of the material attachment point, which determines the resistive torque to the concentric-eccentric range of motion dependent on the degree formed between the segment and the elastic tube (Ribeiro et al., 2005). Thereby knowing the implications of the resistive torque in the effort's characteristic, the overloading progression can be done through the increase of the degree between the segment and the tube, progressing from a lower to a higher degree, resulting in a higher resistive torque with the same 60cm tube. Thus, it increases the load in the end of the range of motion when the muscle presents lower lengths and, therefore, less capable to the strength generation (Sacharuck et al., 2005; Ribeiro et al., 2005).

CONCLUSION

The results obtained through this study confirm the descriptions of studies reported in the literature for Thera-band®-silver elastic tubes. It was observed differences in the tension levels for Auriflex® and Lengruber® national elastic tubes. These tubes have the same thickness and were made with the same type of material. The differences observed in the force level can be related to the polymer employed in its production. As Auriflex as Thera-band elastic tubes presented, values of force and tension superior, respectively to 204 and silver specifications, to data informed in the literature.

The results of this study should be confirmed in more researches which characterize national and imported elastic under situations similar to those guided in practice, establishing the durability of the elastic material submitted to higher load rates than the reported ones, as well as the physiological responses obtained though programs of rehabilitation and sports training.

Besides, effects of temperature, humidity and exposure to the contact, chemical residues, which affect the elastic material durability, they are still unknown, despite being of fundamental importance in swimming, athletics among other sports modalities.

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RELATIONSHIP BETWEEN RESISTANCE AND DURABILITY OF THE ELASTIC TUBES EMPLOYED IN

REHABILITATION AND SPORTS TRAINING PROTOCOLS

The purpose of this study was to determine the relationship between elastic resistance and durability offered by national elastic tubes Auriflex® - 204 and imported elastic tubes Thera-band® - silver used as source of dynamic progress resistance (DPR) in programs of rehabilitation and sports training. The bodies test have been submitted to axial traction tests at 0, 500, 1000, 2000, 3000 loading-unloading cycle. Each of the respective cycling values consisted of 6 bodies test. The loading-unloading cycle reached a maximum strain of 100% from the initial length and a displacement rate of 1800 mm/min (0.5 Hz) and after each test the bodies test were submitted to 300% of strain to obtain the force curve of the elastic tubes. The results obtained through this study confirm the reports of durability for the reference study of the Thera band® manufacturer. The Auriflex® 204 tubes present maximum force values higher than those of Lengruber® 204 tubes, despite they present the same area of transverse section and the same material, which is due to the methods and polymers employed in their production. The Auriflex® 204 tubes of more accessible cost lose their capacity to respond to the same force values after the cycling, although they can replace other imported tubes of better quality from adjusting to the target load.

KEYWORDS: Biomechanics, Traction test, Elastic tubes, Sports training, Dynamic progress resistance

RESISTÊNCIA E FADIGA DE TUBOS ELÁSTICOS UTILIZADOS EM REABILITAÇÃO E TREINAMENTO ESPORTIVO

RESUMO

Poucos estudos têm se ocupado da caracterização mecânica da resistência elástica oferecida ao esforço dificultando a padronização da aplicação da resistência elástica sendo ainda empregada de maneira subjetiva. A proposta deste estudo foi descrever as propriedades mecânicas dos tubos elásticos Thera-band tubing - prata de fabricação americana e os tubos elásticos nacionais Auriflex® 204. Em nossos ensaios foram utilizadas uma amostra composta por 3 corpos de prova de tubos elásticos nacionais (Auriflex® 202) e uma amostra de 3 corpos de prova de tubos importados (Thera-band®-prata). Os corpos de prova foram submetidos a ciclagem em uma máquina de ensaios mecânicos (MTS® 810) a uma taxa de carga 500 mm/min na qual foi obtida a relação tensão-deformação do material elástico. Nossos achados confirmam os relatos do estudo de referência da marca Thera-band®, porém não foram encontrados dados na literatura a respeito dos tubos Auriflex® e apesar da padronização da espessura do material não é observada a mesma padronização quanto à geração de resistência para os tubos elásticos nacionais. Neste estudo são informados dados referentes à quantificação de diferentes tubos elásticos encontrados na literatura, assim como os gráficos e equações preditórias de resistência oferecida pelos tubos aqui testados, além de aspectos relacionados a sua aplicação. Apesar dos dados disponibilizados em nosso estudo e por diferentes autores sobre a força e o percentual de deformação, aspectos como a fadiga e durabilidade do material elástico necessitam de estudos mais detalhados de forma a garantir maior segurança na sua utilização.

PALAVRAS CHAVE: Resistência elástica, Treinamento Resistido, Biomecânica.

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