A Comparative Study on the Material Properties between the Thera-Band and the Chained-Rubber Band

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Background: *Chained-rubber bands have been used as a substitute for Thera-Bands as an exercise tool. Currently, there is no scientific literature that confirms the material properties of the chained-rubber band.*

Objective: *This study evaluates whether the chained-rubber bands have comparable properties to the Thera-Bands.*

Material and Method: *The chained-rubber bands and Thera-Bands were stretched using a mechanical testing machine. Multiple mechanical modalities were evaluated including the reproducibility, effect of velocity, initial length, and cyclic loading. The force-percentage of strain was recorded and evaluated.*

Results: *Chained-rubber bands have similar characteristics as Thera-Bands in terms of pattern of the relation between the force-displacement which displayed linear behavior after a 50% strain and reproducibility (ICC = 0.99). Initial length and velocity had no effect on the Thera-Bands, however it did have an effect on the chained-rubber bands. In the 3,000 cycles of usage, the mean force for stretching on the chained-rubber bands and Thera-Band was reduced by 6.3% and 10% respectively.*

Conclusion: *Chained-rubber bands have similarities to Thera-Bands which can be used as an exercise instrument. But the rehabilitation protocol must be properly adjusted to the limitation of initial length and velocity of exercise. Good guidance must be followed.*

Keywords: *Elastic exercise, Material properties, Rubber band, Rehabilitation*

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There are many studies that confirm the effectiveness of the Thera-Bands in exercise for post-operative patients[1-3]. With a further publication of the Thera-Band's properties[4], resulted in a deeper understanding of the basic knowledge of the Thera-Band[5]. However, in many regions, Thera-Bands are not readily available. An alternative option in dealing with this problem is using the rubber band braided as chained-rubber bands (CRBs) and replace Thera-Bands in rehabilitation protocol[6]. Using rubber bands are easily accessible and economical[6].

Many studies have shown that the CRBs can improve muscle strength and body balance in the elderly as well as postoperative patients[7]. To our knowledge, there are clinical trials supporting the effectiveness of the CRBs as exercise tools but none in basic science that demonstrate the properties of the CRBs that have been constructed to date. Thus, this study evaluates the material properties of the CRBs compared to the Thera-Bands in application for the rehabilitation instrument.

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Material and Method

Study design

This was a comparative controlled experimental study. Red Thera-Bands were used as a control against three different brands of rubber band. The Thera-Bands and CRBs were stretched using a mechanical testing machine in order to identify the following 5 properties: reproducibility, effect of initial length, velocity, loading versus unloading and cyclic loading tests. The force-percentage of strain were recorded and evaluated.

Study materials

Red Thera-Bands from the Hygenic Corporation, USA was used as controls. Five samples of 10 cm length were tested in each test. Except for effect of initial length test, five samples of each 10 and 20 cm length of Thera-Bands were used to match the length of the CRBs in the study.

Rubber bands size (diameter) of 4.8 cm were selected from three companies which are commonly found in grocery store in our area. Five packages of rubber bands from each brand (Apple; Samutsakorn, Thailand (RB1) KS; Pathumthani, Thailand (RB2) and OK; Bangkok, Thailand (RB3)) were obtained (each package contains 3,500-3,530 rubber bands). Six hundred seventy five rubber bands from each brand were randomly selected to braid into the CRB (five samples for each test). One chain included 3 loops. Each loop included 5 rubber bands. Except for the initial length test, the test included of 3 and 6 loops chains. The mean length of the 3 and 6 loops chained-rubber bands are relatively equivalent to the 10 and 20 cm length of Thera-Bands respectively (Fig. 1).

Instrumentation

The table-top type AG-X plus SC 10 kN universal tester, Shimadzu Corporation, Japan was used. The data record was performed at 5 Hz with the TRAPEZIUM X Materials Testing Software. Custom-made metal grips were designed to fit with the CRBs and the Thera-Bands.

Procedure

The starting force was calibrated to zero and the length was recorded as initial length after the material was attached to the custom-made metal grips for 30 seconds. Samples were tested under displacement controls with uniaxial tension at several conditions. The testing material was stretched from 0-300% strain except for loading direction tests which stretched from 0 to 300% strain and continuously went back to zero. All tests were stretched 30% strain/second, which was optimal velocity for rehabilitation purpose, except the effect of velocity tests which used 30% strain/second and 3% strain/second. Cyclic test was stretched sinusoidally from 100-200% strain for 3,000 cycles. We used numbers of cycles that we believe are represented of rotator cuff exercise protocols. Four different exercises with 12 repetitions 2 times per day for 4 weeks would mean 2,688 cycles.

Data collection and statistical analysis

Reproducibility of each material was determined by intra-class correlation coefficient from force-percentages of strain. An effect of each property, including a loading velocity, an initial length and a loading direction was investigated by dividing each elastic band into 2 groups. Mean force differences ($\Delta\overline{F}$) between groups were analyzed using paired t-tests. The effect of cyclic loading was evaluated by measuring mean forces from each material during 4 following cycles; 1^{st} cycle, 1^{st}-$1,000^{th}$ cycle, $1,001^{st}$-$2,000^{th}$ cycle, and $2,001^{st}$-$3,000^{th}$ cycle. Mean force differences ($\Delta\overline{F}$) between the mean forces during each cycle and the mean force at the baseline (1^{st} cycle). All data were analyzed with SPSS 17.0 (SPSS Inc., Chicago, IL, USA). Statistically significant difference was reported for *p*-value <0.05.

Results

Resistance curve

The graph shows that Thera-Bands, RB1, RB2 and RB3 have similar patterns of force-percentages of strain curves which displayed a non-linear behavior during intial 50% stretching phase and linear behavior after 50% strain (Fig. 2).

Reproducibility

All RB1, RB2, RB3 and the Thera-Bands have equivalent property in reproducibility with ICC 0.999 (Table 1).

Effect of initial length

The change of the initial length has no effect on the Thera-Bands 0.88 N; $p = 0.1$ while all rubber bands have been effected RB1 2.48 N; $p<0.001$, RB2 0.97; $p = 0.046$ and RB3 3.29; $p<0.001$ (Table 2).

Fig. 1 The chained-rubber band.

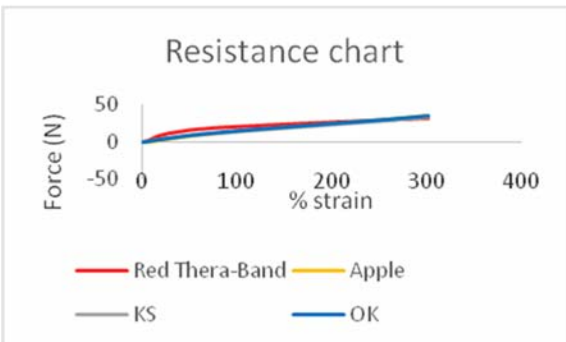

Fig. 2 The relation of force-percent strain.

Effect of velocity

There were no significant changes of the Thera-Bands regardless of the change in velocity = 0.98; p = 0.054. While the force was different in RB1 = 0.94 N; p = 0.028, RB2 = 1.56 N; p = 0.002 and RB3 = 1.29 N; p = 0.001 (Table 3).

Effect of loading and unloading

Only the RB2 rubber bands had no difference for the loading and the unloading = 0.82 N; p = 0.356. While, the force was different in the RB1 = 4.96 N; p<0.001, RB3 = 4.50 N; p<0.001. All samples have force in loading phase higher than unloading phase (Table 4).

Table 1. Intraclass correlation coefficient

Sample	ICC	*p*-value
RB1	0.999	<0.001
RB2	0.999	<0.001
RB3	0.999	<0.001
Thera-Band	0.999	<0.001

Cyclic loading

The force was decreased on the red Thera-Bands by 23% at 2,000th-3,000th cycles when compared with the baseline. But compared to the 2nd-1,000th cycle, the force was reduced by 10%. The RB1, RB2 and RB3 had a force decrease from the baseline 14%, 7% and 21%, respectively, when compared with the baseline.

Comparing to the 2nd-1,000th cycle with the 3,000th cycle the force was reduced 2%, 4% and 13%, retrospectively (Fig. 6).

Discussion

There are clinical trials that confirm the effectiveness of the CBRs[6,7] and prove the same results compared with the Thera-Bands but are relatively lower in cost[8]. However there was no study providing the basic material properties of the CRBs that means the CRBS may not standardized to the Thera-Bands until proven its material properties.

The properties of the red Thera-Band tested in this study as control groups were similar to the prior publications[4]. This demonstrates a resemblances with regards to the testing conditions for the CRBs.

The results show that the CRBs have similar

Table 2. The result of effect of initial length different

Sample	Trial	Slope	$\Delta\overline{F}$	95% CI of difference	*p*-value
RB1	Long	0.12	2.48	1.72-3.24	<0.001
	Short	0.11			
RB2	Long	0.10	0.97	0.22-1.92	0.046
	Short	0.10			
RB3	Long	0.13	3.29	2.98-3.60	<0.001
	Short	0.12			
Thera-Band	Long	0.11	0.88	(-2.98)-3.60	0.100
	Short	0.11			

Table 3. The result of effect of different velocity

Sample	Trial	Slope	$\Delta\overline{F}$	95% CI of difference	*p*-value
RB1	3% strain/sec	0.11	0.94	0.13-1.74	0.028
	30% strain/sec	0.11			
RB2	3% strain/sec	0.10	1.56	0.80-2.33	0.002
	30% strain/sec	0.10			
RB3	3% strain/sec	0.12	1.29	0.67-1.91	0.001
	30% strain/sec	0.11			
Thera-Band	3% strain/sec	0.11	0.98	(-0.03)-2.03	0.054
	30% strain/sec	0.11			

Table 4. The results of effect of loading and unloading

Sample	Trial	FS	$\Delta\bar{F}$	95% CI of difference	*p*-value
RB1	Load	0.11	4.96	3.36-6.02	<0.001
	Unload	0.11			
RB2	Load	0.10	0.82	(-1.12)-2.76	0.356
	Unload	0.10			
RB3	Load	0.12	4.50	3.04-5.97	<0.001
	Unload	0.11			
Thera-Band	Load	0.07	3.39	2.31-4.45	<0.001
	Unload	0.07			

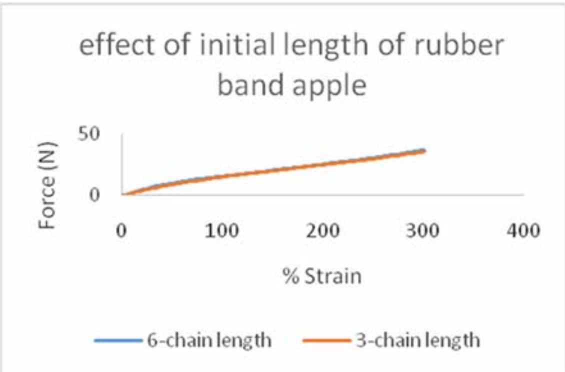

Fig. 3 The relation of force-percent strain of 6-chained and 3-chained length of RB1.

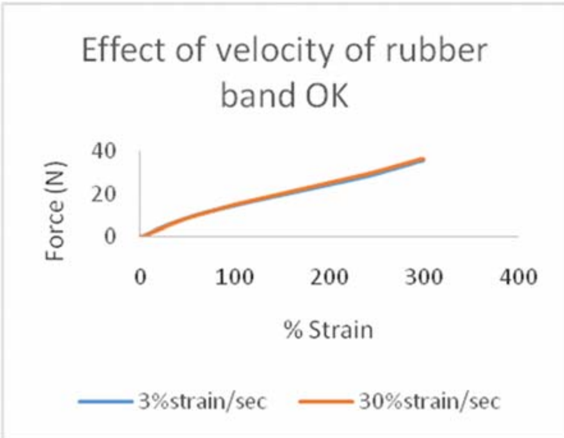

Fig. 4 The result of different velocity of RB3.

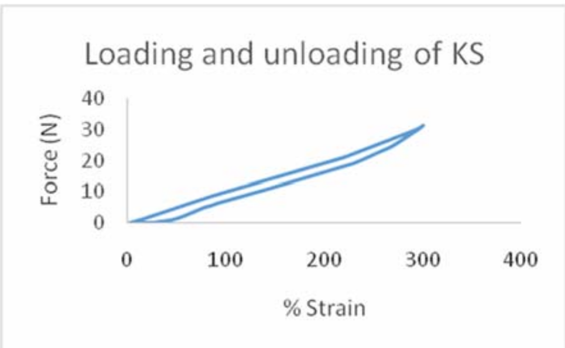

Fig. 5 The relation of loading and unloading of the RB2.

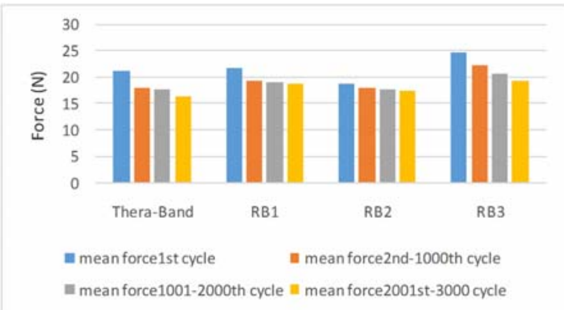

Fig. 6 The cyclic loading test.

properties to Thera-Band in terms of reproducibility and pattern between force and percentage of strain in linear relation after 50% of strain. These two properties are important for patients to reproduce their own CRBs as a tool for rehabilitation which force can be predicted. Furthermore, the constant relation between force and percentage of strain allows the clinicians to decide the proper force for the patients. The CRBs in our study provided this property at the distance between 50-300 percentages of strain. The clinicians should be aware of this limitation. In the other aspects, initial length and velocity have no effect on the Thera-Bands, however there are effects on the CRBs. Clinician must specify the initial length and proper velocity to achieve the proper force to avoid unnecessary injury. For load and unloading test (refer to concentric and eccentric exercises), when compared to Thera-Bands, we found one CRB (RB3) had equal force generated from both phases but the remaining 2 CRBs were the same as the Thera-Bands. In general, because the loading force is higher than unloading in the chained-rubber band, clinicians must realize that the force of eccentric exercise will be less than expected. In order to improve eccentric exercise, the velocity, the initial length or the number of the rubber bands in one loop must be increased. While the Thera-Bands claimed to last long for 6 weeks of exercise in recent study with average force difference between the first and last cycle was –0.22+0.31 (–1.11 to 0.27) N[4]. Our study demonstrates that the rubber bands (RB1, RB2) had less change in the mean force at 3,000 cycles compared to 1,001st-2,000th cycle. This finding implies that the CRBs can be used for at least 4 weeks (3,000 cycles) as same as the Thera-Bands. Nevertheless, in clinical practice, the Thera-Bands are commonly replaced every 3-4 weeks to increase the required target resistance[9]. This study also found that there had a marked decrease in mean force after the first initial stretching. This finding could be explained by a prestretching effect in the study by Patterson et al[4]. It was recommended to stretch at least 20 times to stabilize the material so that it will have the consistent force-generating property. The CRBs also should be stretched before using.

Conclusion

Based on this study, The CRBs can be used in the same rehabilitation protocol as the Thera-Bands regarded that the properties of CRBs were comparable to the Thera-Bands in terms of force displacement and reproducibility. However, the Thera-Bands provide the same strain in various initial length and velocity conditions, while the CRBs need to be adjusted.

Therefore, in the clinical practice, the CRBs need to be used with proper guidance to the patients according to the adjusted rehabilitation protocol with the limitation of initial length and velocity.

What is already known on this topic?

The understanding in basic material properties and several published studies confirmed the effectiveness of the Thera-Bands of which has been purposed as a standard tool for rehabilitation.

There were problems regard to the unavailability of Thera-Bands and its cost in widely market. In many regions developed an alternative material, the chained-rubber bands, to use as the Thera-Bands. The recent studies shown that the chained-rubber bands had the same effectiveness as the Thera-Bands for rehabilitation purpose. However, there are no proper basic material properties of the chained-rubber bands supported.

What this study adds?

This study was designed for proper understanding of the material properties of the chained-rubber bands as the exercising tool. So the clinicians can determine whether to recommend the chained-rubber bands to their patients or how to utilize the chained-rubber bands at its best condition from the knowledge provided in this study.

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Potential conflicts of interest

None.

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การศึกษาเปรียบเทียบคุณสมบัติวัสดุระหว่างยางแผ่นยืด (Thera-Band) กับยางวงร้อย

วรพล เจริญพร, ชลวิช จันทร์ลลิต

ภูมิหลัง: *ปัจจุบันได้มีการนำยางวงร้อยมาใช้ในการบริหาร ซึ่งพบว่าได้ผลดีในลักษณะเดียวกับยางแผ่นยืด (Thera-Band) โดยที่ยังไม่มีการศึกษาลงลึกถึงคุณสมบัติพื้นฐานที่มารองรับการนำยางวงที่นำมาร้อยในลักษณะดังกล่าวมาประยุกต์ใช้*
วัตถุประสงค์: *เพื่อทำการศึกษาว่ายางวงที่นำมาร้อยเป็นเส้นมีคุณสมบัติที่สามารถเทียบเคียงกับยางแผนยืด (Thera-Band) หรือไม่*
วัสดุและวิธีการ: *ได้นำยางวงร้อยและยางแผ่นยืด (Thera-Band) มาทำการดึงยืดด้วยเครื่องทดสอบวัสดุ โดยได้ทำการศึกษาคุณสมบัติเชิงกลต่าง ๆ ที่ส่งผลต่อการบริหารดังนี้ ผลของความเร็วในการดึงยืด, ระยะเริ่มต้น, การดึงยืดและการปล่อยหด, ความสามารถในการทำซ้ำ และการดึงต่อเนื่อง โดยทำการบันทึกแรงต่อร้อยละของความเครียดที่เปลี่ยนแปลงไปและนำมาวิเคราะห์*
ผลการศึกษา: *ยางวงร้อยนั้นมีคุณสมบัติเทียบเคียงยางแผ่นยืด (Thera-Band) ที่สามารถนำมาทำซ้ำได้ (ICC = 0.99) ทั้งยังแสดงลักษณะของแรงต่อร้อยละของความเครียดที่เปลี่ยนแปลงไปโดยมีความสัมพันธ์เป็นความสัมพันธ์เชิงเส้นตรงตั้งแต่ระยะร้อยละที่ 50 อย่างไรก็ตามระยะเริ่มต้นและความเร็วในการดึงยืดนั้นส่งผลต่อแรงที่ใช้ในการดึงยืดของยางวงร้อยแต่ไม่ส่งผลต่อยางแผ่นยืด (Thera-Band) ในการดึงยืดต่อเนื่อง 3,000 รอบนั้นพบว่าแรงเฉลี่ยที่ใช้ในการดึงยืดสำหรับยางวงร้อยและยางแผ่นยืด (Thera-Band) นั้นลดลง 6.3% และ 10% ตามลำดับ*
สรุป: *เนื่องจากคุณสมบัติที่คล้ายกันหลายประการของยางวงร้อยและยางแผ่นยืด (Thera-Band) จึงสามารถนำยางวงร้อยมาใช้ในการบริหารได้ แต่การบริหารนั้นจะต้องมีการปรับระเบียบการในการบริหารให้เหมาะสมโดยให้คำนึงถึงข้อจำกัดจากผลของความเร็วในการดึงยืดและความยาวเริ่มต้น*