Arch AHS

ORIGINAL ARTICLE

Archives of Allied Health Sciences 2022; 34(3): 22-32.

Immediate effects of percussive massage treatment on thoracolumbar fascia thickness: a quasi-experimental design in healthy individuals

Chao Yang[1], Wichai Eungpinichpong[2,3*], Wiraphong Sucharit[2,3], XingYu Huang[4]

[1] Department of Exercise and Sport Sciences, Faculty of Graduate school, Khon Kaen University, Khon Kaen, Thailand.
[2] School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University, Thailand.
[3] BNOJPH Research Center, School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University, Thailand.
[4] Department of Human Movement Sciences, Faculty of Physical Education, Gan Nan noramal University, Gan Zhou, China.

KEYWORDS
Percussive massage;
Vibration massage;
Massage gun;
Thoracolumbar fascia;
Fascia thickness.

ABSTRACT

In recent years, numerous studies have pointed to the integral role of fascial tissue in developing lower back pain. Percussion massage therapy could stretch muscles and connective tissues by generating muscle waves, which may improve the fascial structures and muscle functions and provide new ideas for preventing and treating lower back pain. However, no studies have been conducted to investigate the effects of percussion massage therapy on fascial structure, skin and muscular responses, and lumbar flexibility. This pilot study aimed to preliminarily investigate the effects of percussive massage therapy on thoracolumbar fascia (TLF) thickness, skin temperature, muscle stiffness and pain, and lumbar mobility. A quasi-experimental before-and-after design was obtained in 12 healthy participants aged 20-40. A 15-minute percussion massage was performed on the participants' TLF in the lower back region. All parameters were measured before and immediately after the intervention. The results showed that the maximum thickness value of the TLF decreased significantly after the intervention (p-value < 0.05), whereas the mean thickness value did not change. Shortly after the intervention, skin temperature increased (p-value < 0.05), perceived stiffness decreased (p-value < 0.05), visual analog scale (VAS) and press pain threshold (PPT) decreased (p-value < 0.05), and perceived stiffness decreased (p-value < 0.05). No change in lumbar flexibility was observed (p-value > 0.05). The results indicated that percussive massage therapy may reduce the maximum thickness value of TLF and improve tissue hardness, skin temperature, and pain intensity. A randomized controlled study with a large sample size is suggested to verify these effects.

***Corresponding author:** Wichai Eungpinichpong, PT, PhD. School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University 123, Mitraphab Highway, Muang, Khon Kaen 40002, Thailand. E-mail: wiceun@gmail.com
Received: 12 May 2022/ Revised: 23 August 2022/ Accepted: 18 September 2022

Introduction

More than half of the population worldwide has suffered from low back pain in their lifetime, and it is second only to upper respiratory problems as a symptom-related reason for seeking medical care[1]. The traditional view of lower back pain is attributed to specific sources of pain, such as nerve roots, spinal joints, sacroiliac, and intervertebral disc sources of pain[2]. However, an increasing number of studies have shown that fibrosis and densification of the thoracolumbar fascia (TLF) play an integral role in back pain[3,4]. Previous studies found that patients with chronic lower back pain have thicker TLF and lower TLF shear strain compared to people without lower back pain[5,6] and that disorganization of TLF structure was associated with high levels of lower back pain and disability[7]. Besides, Andrea et al[8] evaluated the quadriceps, Achilles, and plantar fascia in 82 healthy volunteers and found that even among healthy volunteers, 51% had varying degrees of connective tissue thickening. The thickening of the fascia was associated with a negative impact on the mechanical properties and function of the fascial tissue and resulted in limited flexibility[9]. Earlier studies found that the fascia in the sternocleidomastoid area thinned in patients with neck pain after they were treated with manipulation[10]. This may be because mechanical stimulation increased local strain modifying the mechanical properties of the extracellular matrix[4].

The efficacy of manual therapy depends on the level and experience of the therapist, and not everyone has sufficient conditions to receive the treatment of the therapist[11]. Therefore, it is particularly important to find a tool for self-physiotherapy. Handheld percussive guns have been shown to have similar effects to manual therapy and are an effective way to improve muscle tissue[12]. Due to its benefits, the handheld percussive gun (Figure 1) has become popular in both therapeutic and sports communities and has been widely used by professional athletes and sports enthusiasts around the world. It has the advantages of being easy to use, portable, and inexpensive[13], which allow users to treat or care for themselves at home under the guidance of a professional (doctor/physiotherapist/exercise physiologist). Percussive massage therapy has the potential ability to treat muscles and connective tissues (fascia) because it combines the physiological mechanisms of conventional massage and vibration therapy. Percussive massage therapy allows the application of a particular vibration frequency to the muscles, which induces a tonic vibration reflex that promotes profound tissue improvement through changes in muscle tone[14]. In addition, since the fascia is composed of fibroblasts, high-frequency percussion may cause creeping changes in the collagen fibers by continuous cyclic loading, and reversing the fascia's densification[15].

To our knowledge, there are no studies on the effects of percussive massage therapy in the lumbar region. It is necessary to verify the effect of percussive massage therapy on the back in a healthy population before conducting studies on patients with lower back pain. This study aimed to preliminarily investigate the immediate effects of percussive massage treatment on the TLF structural, and mechanical properties of the lower back, as well as the lumbar flexibility in healthy adults. We hypothesized that the percussive massage treatment would result in a decrease in thoracolumbar fascia thickness, and tissue hardness, as well as perceived stiffness and pain intensity, and an increase in skin temperature, and lumbar flexibility.

Materials and methods

Study design

This was a quasi-experiment utilized pre- and post-study design. The experiments were conducted at the Department of Physiology, Khon Kaen University, Thailand from November 25 to December 4, 2020. Baseline data before the intervention and immediately post-intervention (a percussive massage treatment) were collected. Experimental measurements and interventions were performed in a room with the temperature of 26.5 degrees Celsius. The study proposal was approved by the Research Ethics Committee of Khon Kaen University, Number: HE642185.

Participants

The inclusion criteria for participants in this study were 20 – 40 years old males and females, BMI (body mass index) < 30 kg/m^2, and VAS scale of pain intensity ≤ 3 cm. The conditions for exclusion were based on a review of past medical history. Participants with previous health problems and contraindications to have massage (such as low-back pathology, documented disabilities, and pregnancy) were excluded. Finally, twelve participants (6 males, and 6 females) were included. Their mean height, weight, and BMI were 168.17 ± 7.26 cm, 69.6 ± 13.8 kg, and 24.4 ± 3.99 kg/m^2 respectively.

Percussive massage therapy protocol

To maintain the consistency of the intervention, the percussive massage treatments were all conducted by a researcher who had a certified exercise prescription from the Chinese National Sports Administration and was supervised by a physiotherapist. During the percussive massage treatment, participants lay prone on a standard massage bed with a small pillow on the abdomen to ensure relaxation of the back muscles. The researcher used a percussive massage gun (35Hz) to perform 15-minute percussive massage on the erector spinae muscles of the lower back (7.5 minutes per side). He applied the percussive massage treatment on the outermost side of the treated muscle and moved the massage gun in a straight line from the distal end to the proximal end within 30 s. Then he moved the percussive massage gun laterally and then in a straight line from the proximal end to the distal end (Figure 2). The researcher kept trying to apply the same pressure to the skin, and the massage gun never left the skin to ensure continuous percussion vibration.

Figure 1 The handheld percussive massage gun with the different attachment heads: (1) hard ball head, (2) spinal head, (3) hard plain head, and (4) double-spinal head.

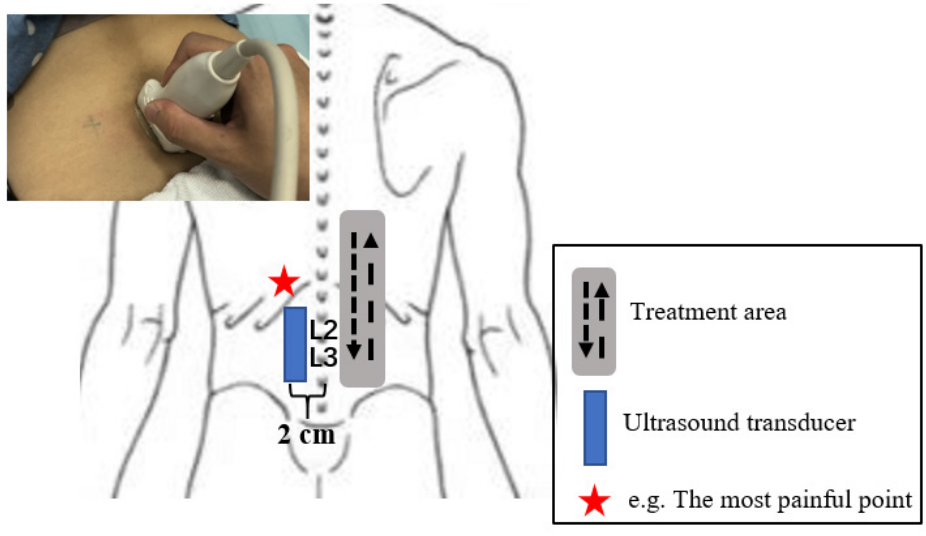

Figure 2 Schematic diagram of the treatment area and measurement points
Note: The intervention was bilateral; the measurement points on the other side are the mirror image of the schematic position. Five-pointed star: measure point of PPT (press pain threshold), tissue hardness.

Outcome measurements

To reduce the confounding effects of measurement, the outcomes were measured in the order starting from skin temperature, then VAS (visual analog scale), PPT (pressure pain threshold), tissue hardness, fascia thickness, perceived stiffness, and lumber flexibility. Measurements of fascia thickness using ultrasound images and PPT were performed by a physiotherapist with eight years of experience and training in ultrasound, and other outcome measures were performed by a trained researcher.

Skin temperature

Skin temperature was measured by using an infrared thermal imaging camera featuring 320·240 pixels with an infrared spectral band of 7.5 – 14.0 mm (Ti10 Fluke Thermal Imaging Camera; Fluke Corporation, Washington). The region of interest (ROI) was the same as the area of the treatment area. The assessor held the instrument so that the lens was parallel to the skin and 40 cm away from the measurement area to obtain the skin temperature[16]. The measurement was repeated three times and the average value was used on both sides for data analysis.

Pain intensity

PPT and VAS were used to assess participants' pain intensity before and after the intervention. The PPT was the minimum amount of pressure that caused discomfort or pain. We measured the PPT using a tissue algometer (Algometer Combo, OE-220 Japan) by vertically placing a 1 cm^2 circular plastic tip over the participant's designated pain point. A physiotherapist palpated the participants' lower back regional provocation points and marked the provocation points where the participants' pain was most pronounced by pressure. Then he gradually applied the pressure to the measurement point at approximately 1 $kg/cm^2/s$ until the participant began to feel pain and pressed the switch button attached to the dynamometer and recorded the corresponding force value (kg/cm^2). The participant was asked to remember this pain level and to apply the same criteria to the subsequent measurement. The lower the score of VAS, the greater PPT felt in the test area[17]. Measurements were repeated three times at 10-second intervals at each side of the measurement point, and the average value of the two sides was taken for data processing. The VAS[18] was used to measure

the intensity of perceived pain by drawing a 10 cm straight line on paper with a ruler and telling participants to draw a line perpendicular to the line according to their perceived back pain during the test, where the leftmost end of the line represented no pain and the rightmost end represented extreme pain. The VAS test was measured before and immediately after the intervention.

Tissue hardness

The measurement of tissue hardness was used with a tissue hardness meter/algometer (Algometer Combo, OE-220 Japan), and measured by placing a plastic disk with a diameter of 10 cm vertically on the painful point (The measurement points were in the same location as PPT. The tissue hardness meter/algometer automatically recorded the tissue stiffness value after low pressure[17], repeated three times, and the average value on both sides was used for data processing.

Fascia thickness

Ultrasound images were acquired by an ultrasound-trained physiotherapist using Hitachi ARIETTA Prologue, Japan, with a 4-cm, 14 MHz linear array transducer for ultrasound imaging of the lumbar spine region. The location of the paravertebral muscles was first determined during real-time ultrasound imaging, and next the ultrasound focus area was adjusted to a superficial border close to the connective tissue. A paraspinal image was acquired bilaterally from the bilateral transducer centered 2 cm from the middle of the L2-L3 interspinous ligament (Figure 1)[5]. The reason was that the fascia was more parallel to the skin at this location than at other areas such as the L4-L5 level, and there was less angular variation between the skin surface and the TLF. This ultrasound-described protocol was a reliable method to determine fascial thickness concerning both intra-observer (ICC: 0.67 – 0.77) agreement and inter-observer (ICC: 0.82 – 0.92) agreement[9,19]. The mean and maximum values of the fascia thickness at that location were recorded separately, and the mean value was evaluated by taking the average of three measurements of the fascial thickness in the proximal, middle, and distal portions of the transducer (Figure 3A). The maximum value of the fascia was averaged by repeating the measurement three times for the thickest part of the fascia on the image (Figure 3B). The thickness of the TLF was collected separately from the left and right sides of the back, and the thickness of the TLF was further calculated by obtaining the mean value of the left and right sums. The measurements were performed with the transducer gently placed on the skin without compressing the soft tissue. The sequence of measurement of bilateral TLF in the left and right order was randomly obtained.

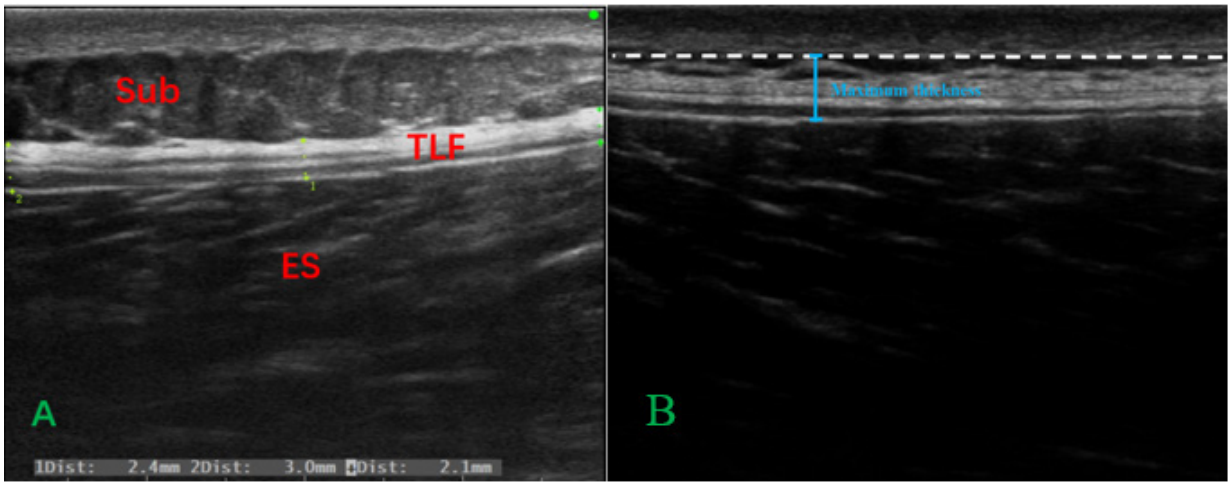

Figure 3 Ultrasound image measurement of mean and maximum values of TLF thickness. (A) Mean value of TLF thickness, (B) Maximum value TLF thickness.

Note: Sub, Subcutaneous layer; TLF, Thoracolumbar fascia; ES, Erector spinae.

Perceived stiffness

Each participant was asked to indicate his or her perceived stiffness scale, a perceived stiffness scale measure consistent with the VAS, ranging from 0 = no stiffness to 10 = most stiffness. Previous research has also shown that this method can be a valid measure of perceived stiffness[20].

Lumbar flexibility

We used a modified Schober test to measure lumbar flexibility because this test could eliminate the errors in the identification of the lumbosacral junction. The measurement covers the entire lumbar spines[21]. The physiotherapist asked the participants to stand up straight and drew a horizontal line connecting the participants' bilateral posterior superior iliac crest marker points. After completing the marking, participants were instructed to bend forward at the waist as if to touch their toes and to ensure that their knees were not bent. The distance between the bottom and the top horizontal line marks was measured using a soft ruler as the participant reached the maximum bend. Fifteen cm subtraction (the original length between the two points) from the collected data for the participant lumbar flexibility value was performed. The validity of the modified Schober test against radiographs was found to be strong (r = 0.97) in a previous study[22].

Statistical analysis

All statistical analyses were performed using the SPSS (version 26.0, SPSS IMB), and the Shapiro-Wilk test was used to verify the normal distribution of data of all variables. Subsequently, if the data were normally distributed, a paired sample t-test was used to detect pre- and post-intervention differences. Wilcoxon sign-rank test was used to detect pre- and post-intervention differences for non-normally distributed data. An alpha level was set at 0.05 to define for the statistical significance of all the tests.

Results

Fascia thickness

Paired samples t-test showed a 9% reduction (p-value < 0.05) in the TLF maximum thickness value after the intervention (Table 1). This indicated that after 15 minutes of percussive massage treatment, the participants' TLF maximum thickness was significantly reduced. For the remaining indicators, we did not find significant changes between before and after the intervention.

Table 1 Comparison of the thoracolumbar lumber fascia measure between baseline and post-test

Fascia Thickness	Baseline (Mean ± SD)	Post-intervention (Mean ± SD)	Differences (Post-Baseline)	95% CI	p-value
Max (mm)	3.85 ± 0.68	3.52 ± 0.47	-0.34 ± 0.53	0.13 – 0.67	0.049*
Mean (mm)	3.07 ± 0.52	3.06 ± 0.47	-0.02 ± 0.42	-0.28 – 0.26	0.901
Lt. Max (mm)	3.91 ± 0.74	3.65 ± 0.53	-0.26 ± 0.47	-0.03 – 0.56	0.077
Lt. Average (mm)	3.23 ± 0.74	3.08 ± 0.54	-0.14 ± 0.39	-0.1 – 0.39	0.226
Rt. Max (mm)	3.79 ± 0.96	3.39 ± 0.48	-0.41 ± 0.87	-0.14 – 0.96	0.125
Rt. Average (mm)	3.06 ± 0.59	2.89 ± 0.35	-0.17 ± 0.63	-5.7 – 0.22	0.352

Note: Values showed means ± standard deviation, (*) is statistically significant, was p-value < 0.05 (2-tailed). Max, maximum value; Mean, mean of the value; Lt., left side of the body; Rt., right side of the body; 95% CI, 95% confidence interval.

Skin temperature

The skin temperature increased by a large magnitude following the percussive massage treatment by 2.34 ± 0.81°C (+8.8%, p-value < 0.01). The results, as shown in table 2, indicated that after 15 minutes of percussive massage treatment, the back skin temperature could be increased.

Pain intensity

For the PPT, the value between pre- and post-intervention was significantly different. (*p*-value < 0.01). The VAS decreased by 48% after percussive massage (*p*-value < 0.01). The results of pain intensity indicated that after 15 minutes of percussive massage treatment, the pain intensity of the participants was significantly relieved.

Tissue hardness

The tissue hardness of the measuring point was a significant difference after intervention (*p*-value < 0.05) (Table 2). Moreover, the tissue hardness change (decrease) between pre- and post-intervention was 1.96 ± 2.88 % (*p*-value < 0.05).

Lumbar flexibility

After the intervention, Schober test value increased by 10% (Table 2), but within-group pre- and post-comparisons did not reveal a statistical significance (*p*-value > 0.05).

Perceived stiffness

For the stiffness scale, statistical analysis showed that participants perceived stiffness decreased by 2 ± 1.46 cm (*p*-value < 0.01). This result indicated that the participants perceived the stiffness improved after the intervention.

Table 2 Comparison of the clinical outcomes measures between baseline and post-test

Parameters	Baseline (Mean ± SD)	Post-intervention (Mean ± SD)	Differences (Post-baseline)	95%CI	*p*-value
ST (ºC)	33.3 ± 1.02	35.6 ± 1.09	2.34 ± 0.81	-2.86 – -1.83	0.001*
PPT (kg/cm^2)	3.65 ± 0.93	4.58 ± 1.11	0.93 ± 0.95	-1.54 – -0.33	0.006*
TH (%)	61.5 ± 4.80	59.8 ± 5.79	-1.96 ± 2.88	-0.95 – 4.52	0.038*
LF (cm)	7.97 ± 3.45	8.59 ± 3.25	0.63 ± 1.59	-1.64 – 0.38	0.199
VAS (cm)	1.77 ± 1.10	0.93 ± 0.64	-0.85 ± 0.77	0.36 – 1.33	0.003*
PS (cm)	3.54 ± 2.08	1.53 ± 1.99	-2.00 ± 1.46	1.08 – 2.93	0.003*

Note: Values showed means ± standard deviation, (*) is statistically significant, was *p*-value < 0.05 (2-tailed). ST, skin temperature; PPT, pressure pain threshold; TH, tissue hardness; LF, lumbar flexibility; VAS, visual analog scale; PS, perceived stiffness; 95% CI, 95% confidence interval.

Discussion

This study aimed to preliminarily examine the immediate effects of percussive massage treatment on TLF thickness, and mechanical properties of the lower back, as well as the lumbar flexibility in healthy adults. We found that after the percussive massage treatment the participants showed a decrease in the maximum thickness value of TLF (*p*-value < 0.05), an increase in skin temperature, and significant improvements in pain intensity, muscle stiffness, and perceived stiffness, but no changes were found in the mean thickness of fascia or lumbar mobility (*p*-value > 0.05).

Abnormalities in the body's movement patterns can lead to local imbalances in muscle tone, with the fascia adapting to the increased regional tension in a denser and more parallel fiber arrangement. Prolonged abnormalities in the fascia can induce inflammation, fibrosis, and densification[4]. In this condition, the concentration of hyaluronic acid in the loose connective tissue becomes viscous, increasing the distance between the fascial layers (fascial thickening)[23], resulting in adhesions in the tissue structure, further affecting the stiffness and mobility of the tissue[5]. In the current study, the maximum, and mean TLF thicknesses observed at baseline values were 3.85 ± 0.68 mm, and 3.06 ± 0.47 mm respectively. These

results were similar to the TLF thickness values of 3.7 ± 0.04 mm for males and 4.1 ± 0.03 mm for females reported by Langevin et al[6].

The single most striking observation to emerge from the data comparison was the maximum value of TLF thickness was decreased immediately after the percussive massage treatment. However, these data must be interpreted with caution, as we did not find changes in the remaining fascial indicators. Firstly, one possible reason for the decrease in maximum fascial thickness could be that percussive massage therapy stretches muscle fibers and fascia by generating continuous muscle waves through constant tapping[24]. Xiong et al[25] found stretching could decrease skin thickness and increase subcutaneous tissue motility in mice (n = 48), possibly due to reduced expression of CCL2 and ADAM8 in the skin. Secondly, stretching also affected connective tissue of inflammation regression. Thirdly, the densification of loose connective tissue was a factor in the thickening of TLF[3,4]. Previous research has established that the structural properties of the loose connective tissue change with increasing temperature, and the three-dimensional superstructure of the HA chains stabilized gradually decomposes when the temperature rises to about 40 ºC[26]. This was consistent with the results we found that we observed a significant increase (p-value < 0.01) (Table 2) skin temperature after a percussive massage treatment, which could support this hypothesis. Statistical analysis showed a significant decrease in tissue stiffness (p-value < 0.05) and perceived stiffness (p-value < 0.01) (Table 2), probably because percussive massage therapy reduced the viscosity of the sparse connective tissue within the fascia. It might increase sliding between the collagen fibrous layers of the deep fascia, and reduce the surrounding tissue stiffness[4].

This study did not find a significant difference in lumbar flexibility after a percussive massage treatment. This outcome was contrary to that of Konrad et al[13] who found the range of motion (ROM) of plantar flexor muscles increased significantly by 5.4% after 5 minutes of percussive massage treatment (54HZ) on the calf muscles. On the one hand, this discrepancy could be attributed to the frequency used in our study was 35HZ, which was much lower than that in the study of Andreas et al[27]. On the other hand, due to the present study ultrasound image acquisition was centered 2 cm from the middle of the L2-L3 interspinous ligament (located on the erector spinae muscle), for better observing the immediate effects of percussive massage treatment, we intervened only on the erector spinae muscles of the lower back. In fact, the TLF blends aponeurotic and fascial planes, which cover the multifidus, lumbar square, and erector spinae muscles, and also connects the abdominal muscles to the gluteal muscles. Thus, the absence of differences in the flexibility before and after the intervention may be due to the incomplete area of the TLF intervention.

Concerning the pain intensity, the percussive massage treatment shown in results had positive changes in pressure pain threshold and VAS (p-value < 0.01) (Table 2). This finding was in consistent with Romero-Moraleda[28] who observed after 5 minutes of vibratory foam rolling on the thigh muscles of a healthy female, and found a significant decrease in both PPT and VAS. This result may be explained by the Gate control theory[29]. The vibratory stimuli pass through large size afferent fibers to establish inhibitory control of pain pathways[30], and the increase in blood circulation and temperature[31] after a percussive massage could accelerate the turnover of pain mediators, such as substance P[30]. The present study also had some limitations, since this was our initial pilot study and did not have a randomized control group. We did not know whether any changes in each of the parameters were due to the intervention or resting posture. However, we may use the results to calculate the sample size and conduct a randomized controlled trial in the future. The participants in this study were healthy adult. Although thickening of connective tissue also occurs in healthy individuals[8], it was still only a small amount compared to patients with chronic lower back pain[5]. It would be interesting to further study the effects of this intervention

in lower back patients. Moreover, TLF thickening is due to fibrosis of the connective tissue, which is a long-term process[27]. Further, longer-term intervention studies are needed to determine long-term effects. Lastly, concerning the frequency of vibration, we only used the frequency of 35HZ for 15 minutes of intervention on the erector spinae of the lower back and found some beneficial effects. It would be interesting to investigate whether different frequency of intervention would produce different results or not.

Conclusion

This novel evidence suggests that 15 minutes of percussion massage therapy could improve maximum TLF thickness values, tissue stiffness, perceived stiffness, and pain intensity in healthy adults but could not reveal changes in mean TLF thickness or lumbar spine flexibility. Although this study has provided some new knowledge of percussive massage therapy on healthy participants, its effects on patients are not well known. Further study with randomized controlled trial in low back pain patients are recommended to explore the effects of vibration therapy.

Take home messages

The present study provides preliminary evidence that a 15-minute back percussion massage therapy reduced the maximum thickness values of the thoracolumbar fascia in healthy adults whereas there were no changes in the mean TLF thickness values. Also, a significant increase in skin temperature was found, as well as improvements in tissue stiffness, perceived stiffness, and pain intensity. Further studies in low back pain patients are warranted.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

We would like to thank the Faculty of Graduate School and Faculty of Associated Medical Sciences, Research Center in Back Neck and Other Joint Pain Research Group, and Khon Kaen University for financial supporting this project. Also thanks to Prof. Dr. Wichai Eungpinichpong for the design of this study, and physiotherapist Wiraphong Sucharit for his help in collecting the ultrasound data, and Assoc. Prof. Dr. XingYu Huang for the analysis of the data in this article.

References

1. Deyo RA, Weinstein JN. Low back pain. N Engl J Med 2001; 344(5): 363-70.
2. Allegri M, Montella S, Salici F, Valente A, Marchesini M, Compagnone C, et al. Mechanisms of low back pain : a guide for diagnosis and therapy. F1000Res 2016; 5: 1-11.
3. Wilke J, Schleip R, Klingler W, Stecco C. The lumbodorsal fascia as a potential source of low back pain: A Narrative Review. Biomed Res Int 2017; 2017: 1-6.
4. Pavan PG, Stecco A, Stern R, Stecco C. Painful connections: Densification versus fibrosis of fascia. Curr Pain Headache Rep 2014; 18(8): 1-8.
5. Langevin HM, Stevens-Tuttle D, Fox JR, Badger GJ, Bouffard NA, Krag MH, et al. Ultrasound evidence of altered lumbar connective tissue structure in human subjects with chronic low back pain. BMC Musculoskelet Disord 2009; 10(1): 1-9.
6. Langevin HM, Fox JR, Koptiuch C, Badger GJ, Greenan- Naumann AC, Bouffard NA, et al. Reduced thoracolumbar fascia shear strain in human chronic low back pain. BMC Musculoskelet Disord 2011; 12(203): 1-11.
7. Almaz J, Daniel L, Romero-morales C, Bravo-aguilar M, Calvo-lobo C. Quantitative ultrasound imaging differences in multifidus and thoracolumbar fasciae between athletes with and without chronic lumbopelvic pain : a case-control study. J Clin Med 2020; 9(8): 1-20.

8. Di Matteo A, Filippucci E, Cipolletta E, Martire V, Jesus D, Musca A, et al. How normal is the enthesis by ultrasound in healthy subjects? Clin Exp Rheumatol 2020; 38(3): 472-8.
9. Wilke J, Macchi V, De Caro R, Stecco C. Fascia thickness, aging and flexibility: is there an association? J Anat 2019; 234(1): 43-9.
10. Stecco A, Meneghini A, Stern R, Stecco C, Imamura M. Ultrasonography in myofascial neck pain: Randomized clinical trial for diagnosis and follow-up. Surg Radiol Anat 2014; 36(3): 243-53.
11. Moyer CA, Rounds J, Hannum JW. A meta-analysis of massage therapy research. Psychol Bull 2004; 130(1): 3-18.
12. García-Sillero M, Benítez-Porres J, García-Romero J, Bonilla DA, Petro JL, Vargas-Molina S. Comparison of interventional strategies to improve recovery after eccentric exercise-induced muscle fatigue. Int J Environ Res Public Health 2021; 18(2): 1-11.
13. Konrad A, Glashüttner C, Reiner MM, Bernsteiner D, Tilp M. The acute effects of a percussive massage treatment with a hypervolt device on plantar flexor muscles' range of motion and performance. J Sport Sci Med 2020; 19(4): 690-4.
14. Guang H, Ji L, Shi Y. Focal vibration stretches muscle fibers by producing muscle waves. IEEE Trans Neural Syst Rehabil Eng 2018; 26(4): 839-46.
15. Comeaux Z. Dynamic fascial release and the role of mechanical/vibrational assist devices in manual therapies. J Bodyw Mov Ther 2011; 15(1): 35-41.
16. Chatchawan U, Jarasrungsichol K, Yamauchi J. Immediate effects of self-thai foot massage on skin blood flow, skin temperature, and range of motion of the foot and ankle in type 2 diabetic patients. J Altern Complement Med 2020; 26(6): 491-500.
17. Zheng Z, Wang J, Gao Q, Hou J, Ma L, Jiang C, et al. Therapeutic evaluation of lumbar tender point deep massage for chronic non-specific low back pain. J Tradit Chinese Med 2012; 32(4): 534-7.
18. Downie WW, Leatham PA, Rhind VM, Wright V, Branco JA, Anderson JA. Studies with pain rating scales. Ann Rheum Dis 1978; 37(4): 378-81.
19. De Coninck K, Hambly K, Dickinson JW, Passfield L. Measuring the morphological characteristics of thoracolumbar fascia in ultrasound images: An inter-rater reliability study. BMC Musculoskelet Disord 2018; 19(1): 1-6.
20. Siegmund LA, Barkley JE, Knapp D, Peer KS. Acute effects of local vibration with biomechanical muscle stimulation on low-back flexibility and perceived stiffness. Athl Train Sport Heal Care 2014; 6(1): 1-9.
21. Wright V. The measurement of back movement. Rheumatology 1983; 22(4): 193-6.
22. Rezvani A, Ergin O, Karacan I, Oncu M. Validity and reliability of the metric measurements in the assessment of lumbar spine motion in patients with ankylosing spondylitis. Spine (Phila Pa 1976) 2012; 37(19): 1189-96.
23. Tadmor R, Chen N, Israelachvili JN. Thin film rheology and lubricity of hyaluronic acid solutions at a normal physiological concentration. J Biomed Mater Res 2002; 61(4): 514-23.
24. Caliandro P, Celletti C, Padua L, Minciotti I, Russo G, Granata G, et al. Focal muscle vibration in the treatment of upper limb spasticity: A pilot randomized controlled trial in patients with chronic stroke. Arch Phys Med Rehabil 2012; 93(9): 1656-61.
25. Xiong Y, Berrueta L, Urso K, Olenich S, Muskaj I, Badger GJ, et al. Stretching reduces skin thickness and improves subcutaneous tissue mobility in a murine model of systemic sclerosis. Front Immunol 2017; 8(124): 1-11.
26. Matteini P, Dei L, Carretti E, Volpi N, Goti A, Pini R. Structural behavior of highly concentrated hyaluronan. Biomacromolecules 2009; 10(6): 1516-22.
27. Schilder A, Magerl W, Hoheisel U, Klein T, Treede RD. Electrical high-frequency stimulation of the human thoracolumbar fascia evokes long-term potentiation-like pain amplification. Pain 2016; 157(10): 2309-17.

28. Romero-Moraleda B, González-García J, Cuéllar-Rayo Á, Balsalobre-Fernández C, Muñoz-García D, Morencos E. Effects of vibration and non-vibration foam rolling on recovery after exercise with induced muscle damage. J Sport Sci Med 2019; 18(1): 172-80.
29. Melzack R, Wall PD. Gate Control-Pain mechanisms - a new theory. Science 1965; 150: 971-9.
30. Guieu R, Tardy-Gervet MF, Giraud P. Substance P-like Immunoreactivity and Analgesic Effects of Vibratory Stimulation on Patients Suffering From Chronic Pain. Can J Neurol Sci 1993; 20(2): 138-41.
31. Lu X, Wang Y, Lu J, You Y, Zhang L, Zhu D, et al. Does vibration benefit delayed-onset muscle soreness?: a meta-analysis and systematic review. J Int Med Res 2019; 47(1): 3-18.