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Evaluation of the effect of ultrasonic heating and exercise heating on muscles by ultrasound elastography: An experimental clinical trial

Egzersizle ısıtma ile ultrasonik ısıtmanın kaslarındaki etkisinin ultrason elastografi ile değerlendirimi: Deneysel bir klinik çalışma

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Abstract

Aim: Ultrasound (US) has been used for therapeutic purposes for many years due to its biological beneficial effects. İn this report we compare the effect of therapeutic ultrasonic heating with exercise-heating on the gastrocnemius / soleus muscles by quantitative measurements of ultrasound elastography.

Methods: İt is designed as a single blind experimental clinical study. Fourty (40) healthy male patients aged between 19-23 years were included randomly in the study. To the first group, we applied a continuous wave therapeutic US on both calfs (symmetrically) consisting gastrocnemius / soleus muscle groups at a frequency of 3 Mhz, 2 w / cm^2 dose, for 6 minutes. To the second group, we applied a 15-minute jogging exercise program. Bilateral, symmetric measurements were made in the first 5 minutes with a wide band linear probe, US elastography before and after application.

Results: A statistically significant decrease in ultrasound elastography strain value (UESV) after therapeutic US in gastrocnemius / soleus muscle groups was observed ($p < 0.001$ / $p < 0.001$). There was no statistically significant change in UESV in the gastrocnemius / soleus muscle groups in the jogging group ($p = 0.792$ / $p = 0.187$). When the percentages of ultrasound elastography strain ratio (UESR) were examined, there was a significant difference in the change of percentages in the gastrocnemius / soleus muscle groups in both groups ($p = 0.005$/ $p = 0.001$). According to this, in both muscle groups, the elasticity increased and the stiffness decreased in group 1 and in group 2, the stiffness increased in some cases and decreased in some, and in overall it was observed to increase.

Conclusion: Therapeutic US-heating is an effective, reliable method that generally increases elasticity and reduces stiffness in calf muscles than exercise-heating.

Keywords: Sonoelastography, Therapeutic ultrasound, Therapy, Exercise

Öz

Amaç: Ultrason (US), biyolojik yararlı etkileri nedeniyle yıllarca tedavi amaçlı kullanılmıştır. Bu yazıda gastroknemius / soleus kaslarının egzersizle ısıtma ile terapötik ultrasonik ısıtmanın etkisini ultrason elastografi (UE) ile kantitatif ölçümleri karşılaştırdık.

Yöntemler: Çalışma tek kör deneysel klinik olarak tasarlanmıştır. Çalışmaya 19-23 yaşları arasında 40 sağlıklı erkek hasta randomize dahil edilmiştir. İlk grupta, 3 MHz frekansında gastroknemius / soleus kas gruplarını içeren her iki kalf kasları (simetrik olarak) üzerine 6 dakika, 2 w / cm^2 doz sürekli akım terapötik US uyguladık. İkinci gruba 15 dakikalık koşu egzersiz programı uyguladık. Bilateral, simetrik ölçümler ilk 5 dakikada geniş bant lineer prob, US elastografi ile uygulama öncesi ve sonrası yapıldı.

Bulgular: Gastroknemius / soleus kas gruplarında terapötik US sonrası ultrason elastografi strain değerinde (UESV) istatistiksel olarak anlamlı bir düşüş gözlendi ($p <0,001$ / $p <0,001$). Koşu grubundaki gastroknemius / soleus kas gruplarında UESV'de istatistiksel olarak anlamlı bir değişiklik yoktu ($p = 0,792$/ $p = 0,187$).

Ultrason elastografi gerim oranının (UESR) yüzdeleri incelendiğinde, her iki grupta da gastroknemius / soleus kas gruplarında yüzde değişiminde anlamlı bir fark vardı ($p = 0,005$ / $p = 0,001$). Buna göre, her iki kas grubunda da elastikiyet artmış ve grup 1'de ve grup 2'de sertlik azalmış, bazı durumlarda sertlik artmış iken bazılarında azalmış ve genel olarak artmıştı.

Sonuç: Terapötik US-ısıtma, genel olarak elastikiyeti arttıran ve baldır kaslarındaki sertliği egzersiz-ısıtmaya göre azaltan etkili ve güvenilir bir yöntemdir.

Anahtar kelimeler: Sonoelastografi, Terapötik ultrason, Terapi, Egzersiz

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Introduction

Heat is widely used to relieve pain in locomotor system diseases. Ultrasound (US) has been used for therapeutic purposes for many years due to its biological beneficial effects [1]. With therapeutic US, adverse bioeffects such as burns and serious bleedings may develop. For this reason, treatment should be started after considering the reduction of side effects, standardization, dosing and benefit-loss ratio [2,3]. Although US is a frequently used therapeutic agent in musculoskeletal injuries, there is limited number of clinical trials and guides to use.

Different exercise types were used in treatment modalities due to their numerous positive effects on muscles and tendons. In some studies it was demonstrated that stretching can reduce muscle stiffness and increase muscle elasticity by altering fascicule strain but not resting fascicule length [4]. Also exercise has fewer side effects and

is not affected by different users than US.

There is insufficient data on the effect of therapeutic-US on muscle elasticity. Although both US and exercise are commonly used in musculoskeletal disorders, the effects and treatment protocols are not fully established. The development of ultrasound technology resulted in the emergence of ultrasound elastography (UE) that can directly measure the mechanical properties of tissue, including muscle stiffness. When elasticity increases, we may say that stiffness decreases in the tissue. In our study, we were able to measure the changes in muscle tissue with therapeutic US-heating by UE quantitatively and compared the results with the changes occurred after jogging exercise. For the first time in the literature, we compared the effect of therapeutic US-heating on the elasticity of calf muscles with exercise-heating by UE quantitatively.

Materials and methods

Cases

It is designed as a single blind experimental clinical study. Forty (40) male cases aged between 19-23 years were included in the study. The US group consisted of 20 males and the jogging group consisted of 20 males of similar age, height and weight range. Those with known musculoskeletal complaints, deformities and sensorial deficits were not included in the study.

In the first group we applied continuous wave US at a frequency of 3 Mhz, 2 w / cm^2 dose for 6 minutes, onto the both calf, gastrocnemius / soleus muscle groups. In the second group, we applied a 15-minute jogging exercise program. Bilateral and symmetric measurements were performed with a broad band linear probe, sonoelastography before and after application. Ultrasound elastography strain value (UESV), strain ratio (UESR) values were calculated.

Therapeutic ultrasound

In our study, we performed continuous wave US (Chattanooga Intelect Mobile US, ELSA, Orthopedics) application at 3 Mhz frequency, 2 w / cm^2 dose, for 6 minutes. We used a gel to provide the skin to stay intact. No adverse effects due to the US were observed in any of the patients.

Ultrasound elastography (UE)

UE technique is a new functional US imaging technique developed in the last 5 years that can demonstrate the distribution of tissue elasticity. The low strain ratio indicated the decrease in tissue elasticity, softening of the tissue, loss of tendon integrity, and decrease in quality. Unlike other methods, this technique provided dynamic data [5].

A high-resolution ultrasonography system (AplioTM 400 Platinum, Toshiba Medical Systems Corporation, Tochigi, Japan) and a broad band convex probe (PVT-375BT) were used by a same trained radiologist. The gray-scale ultrasonographic posterior images of the calf region were obtained symmetrically, bilaterally, and separately. The elastography mode was activated, and pressure was applied when the muscles were captured in the same image during compression phase. The UE strain value (UESV) of the subcutaneous fat tissue in the same image and UESV of the central segments of the calf muscles were detected using the ROI. The UE strain ratio (UESR) of the muscles was calculated by dividing the fat values by the muscle values. All procedures were performed by the same experienced radiologist who was kept uninformed about the clinical diagnosis.

Statistical analysis

All statistical analyses were carried out using IBM SPSS version 19 (IBM Corp., Armonk, NY, USA). Descriptive data were presented in mean ± standard deviation (SD) or median scores according to their categories and distribution. The coherence of variables to normal contribution (normality) was analyzed by Shapiro Wilk test. The Pearson correlation analysis was used to analyze the level of the correlation between the variables.

Categorical data are reported as percentages and are compared using the chi-squared test. Continuous data are reported as mean with standard deviation or median with minimum and maximum and compared using parametric/non-parametric tests according to their normal or abnormal distribution. We also used histogram for this. A p value of <0.05 was considered statistically significant. As a result of the power analysis performed, the minimum number of subjects required in each group was determined as 20 so that the difference of 0.05 units between the two group could be statistically different. Type 1 error = 0.01, power of the test: %75. The study approved by local ethic committee (No: 2016/146) and complied with Helsinki declaration principles.

Results

Forty (n=40) male cases aged between 19-23 years were included in the study. Both groups consisted of 20 male cases. The groups were similar in terms of age, weight and height (p = 0.13 / p =0.06 / p = 0.15). Descriptive data were shown at Table 1. The results of UESV before and after the administration of US onto gastrocnemius / soleus muscles in the US group and jogging group were summarized in Table 2. According to the data, a statistically significant decrease in UESV after US was observed in gastrocnemius / soleus muscle groups (p <0.001 / p < 0.001). In the jogging group, UESV were not statistically different in gastrocnemius / soleus muscles (p = 0.792 / p = 0.187). When the percentages of UESR were examined, there was a significant difference in the change of percentages in the gastrocnemius /

soleus muscle groups in both groups (p = 0.005/ p = 0.001) (Table 3) (Figure 1, 2).

Table 1: Descriptive data of the study

Group	Age (year)	Height (cm)	Weight (kg)
US n/ Mean±std	40/21.10±1.36	40/174.41±5.64	40/71.53±10.96
Jogging n/ Mean±std	40/20.56±1.80	40/176.5±4.40	40/68.38±8.45
t/p	1.51/0.13	1.84/0.06	1.43/0.15

US: ultrasound, t: t value, p<0.05 statistically different

Table 2: UE strain values of gastrocnemius/soleus muscles in US and jogging groups, before/after

US group	n/ mean±std	t	p
GC_1	40/1.11±0.87	4.73	<0.001
GC_2	40/0.43±0.26		
SU_1	40/1.75±1.17	3.89	<0.001
SU_2	40/0.88±0.79		
Jogging group			
GC_1	40/0.55±0.38	0.26	0.792
GC_2	40/0.52±0.61		
SU_1	40/0.72±0.58	1.32	0.187
SU_2	40/1.05±1.46		

US: ultrasound, GC_1: gastrocnemius first, GC_2: gastrocnemius second, SU_1: soleus first, SU_2: soleus second, t: t value, p<0.05 statistically different

Table 3: The percental changes (UESR) in gastrocnemius/soleus muscles in US and jogging groups

Group, n=40	Gastrocnemius %	Soleus %
US	47.44±23.34	49.59±23.86
Jogging	161.80±251.74	188.9±270.66
t	2.86	3.24
P	0.005	0.001

US: ultrasound, UESR: ultrasound elastography strain ratio, t: t value, p<0.05 statistically different

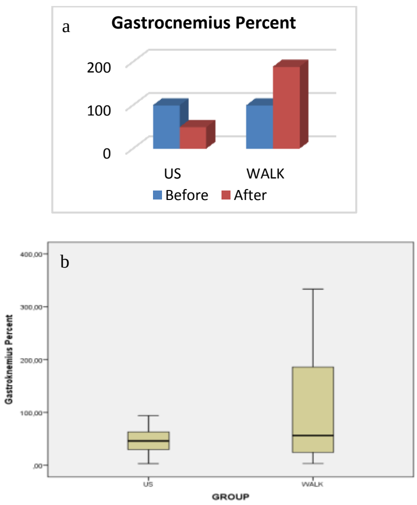

Figure 1a, 1b: Graphical presentation of percent changes in ultrasound elastography strain ratio in gastrocnemius muscle in ultrasound and jogging group

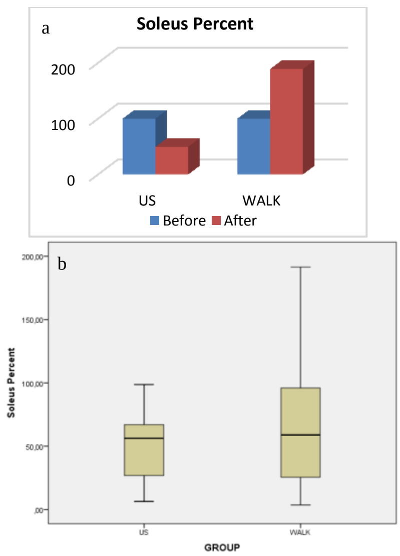

Figure 2a, 2b: Graphical presentation of percent change in ultrasound elastography strain ratio in soleus muscle in ultrasound and jogging group

Discussion

Therapeutic US is the most commonly used electro-physical agents in clinical practice [2]. It is totally different from the diagnostic US and is used in the treatment of diseased or damaged parts of the body. The US waves used in clinics have 0.8-3 MHz frequency and the average treatment dosage is 1.5 w / cm². The maximum dose can be 3 w / cm²; higher doses can be used for the studies. In practice it is very important to use the head probe fully aligned. Water, petroleum jelly, various pomades, jellies can be used for this contact. Ultrasound can be applied in water for uneven surface areas such as hands, feet, elbows. One session takes 5-15 minutes once a day or every other day [6,7].

The impact of US on tissue has been a research topic for half a century. US effects cell tissue via thermal, shock wave and cavitation mechanisms [8]. While high-frequency applications benefit from both thermal and mechanical effects; the heat effect occurs more at low frequencies [9]. Due to the developments such as tranducer design, more accurate measurements and calibrations of acoustic power have been accomplished, US is started to be used in physiotherapy, surgery, chemotherapy and drug delivery etc.

The US is absorbed and it passes through the homogeneous tissues and transforms into heat energy. Heat can be effective on pain by increasing endorphins. US changes tissue metabolism. Increased circulation with vasodilatation helps to remove pain-stimulating metabolic waste [9,10]. Recent publications have shown that therapeutic US can pass cell membrane and induce various intracellular biochemical reactions as well as increase in cell proliferation, angiogenesis and results changes in DNA molecules, protein expression [10-12].

Topics such as dosimetry, transducer selection, duration, and safety for observing the physiological effects of therapeutic US have been the subject of various in vivo animal and in vitro artificial models [11,12]. Usually US thermal therapy appears to be disadvantaged over bones, but with appropriate application techniques, planar US can provide the required heat levels in the soft tissue under the bone in areas such as neck, shoulder, and head [13,14]. Therapeutic US has been used to treat the damage of joints, nerves and tendons. Some of the emitted radiation is absorbed by the healthy tissues around, like muscles.

Ohwatashi et al. [15] studied on a phantom, which is composed of pigskin and tissue-like material, was measured by ThermoGraph after application of 2.0 w / cm, 5 min US, ranging from 1-3 MHz. At 1 MHz application, the maximum temperature was measured in the near of the transducer, at 3 MHz application while the maximum temperature was found to be at bone tissue. Norte et al. [16] found that in arthroscopic knee joints, therapeutic US application to Hofman reflex, was observed to modulate the arthrogenic response according to SHAM.

After 3 hours of low-frequency therapeutic US application to triceps surae muscles of healthy volunteers, an increase of 3-4.0 ° C in temperature observed at a depth of 3 cm at the end of 1 hour [17]. In the case of Vasquez et al [18], after the continuous application of US administration, hypertrophy in the gastrocnemius muscle fibers was found to be excessive; it has to be used in pulsed, focused modes to minimize the damage to the surrounding tissues. Montomery et al [19] have concluded that 20 min at 3.3 MHz, 1.5 w / cm^2 density can be used for therapeutic purposes without heating up.

There are only a few human studies about the effect of the US on muscle tissue. There is not enough guidance about the application method, severity and frequency of US application for muscle tissue, and safety precautions. In our study, we performed continuous wave ultrasound at a frequency of 3 Mhz, 2 w / cm^2 dose for 6 minutes period. As a result, we generally achieved positive results such as increase in the elasticity and reduced stiffness of calf muscles. Berko et al [20] found that elasticity significantly increases immediately postexercise in both biceps brachii and rectus femoris; resting differences between biceps brachii and rectus femoris elasticity, and dominant and nondominant biceps brachii elasticity, do not persist after exercise. Also they found the change in muscle elasticity with exercise is higher in younger children. In our study, we did not observe a significant difference in elasticity and stiffness in muscle groups after the exercise warming. In addition, when percentage ratios were examined, we generally concluded that the exercise was not effective as a heating method.

In both groups of muscles, the elasticity increased with US application and the stiffness decreased and additionally total stiffness decreased compared to the initial state. In the jogging group, the stiffness increased in some cases, but in general an absolute increase was observed. Accordingly, the US is a standard effective method of heating besides jogging exercise was not found effective.

Limitation of the study

Continuous US is generally used to produce thermal effects and reaches deeper than most superficial heating agents. However, although US is well-suited to heating tendons, ligaments, joint capsules and fascia; it is generally not the ideal agent for heating muscle tissue since muscle tissue has a relatively low absorption coefficient. Also, the muscles used in this study are large muscles, and the available US transducers may not be appropriate for heating these muscles.

Conclusion

Increased elasticity in gastrocnemius / soleus muscle groups with therapeutic US-heating was found to be superior to exercise-heating by US elastography.

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