Research Article

Effects of Synergistic Massage and Physical Exercise on the Expression of Angiogenic Markers in Rat Tendons

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Physical exercise and massage are regarded as key factors in regulating tendon structure. However, information on the mechanism through which massage influences the structure and biology of a tendon is scarce. In this study, we attempted to define the impact of these two activities on rat tendons by using morphological and molecular techniques, determining the expression of VEGF-A, FGF-2, and CD34 in the tendons of rats subjected to 10 weeks of physical exercise (running) with massage of varied duration. The group of rats that was trained and massaged during the entire study was characterized by the highest expression of these markers, compared to the rats subjected to massage before training and to the control group subjected to physical exercises only. The greatest significant differences, compared to the control, were noted in the expression of all the studied markers at mRNA level, and in the case of VEGF-A, at protein level, in the third and fifth weeks of the experiment. The results of this study could point to the synergistic impact of simultaneous massage and physical exercise on the expression of angiogenesis markers in rat tendons.

1. Introduction

Tendons are responsible for transferring the forces exerted by muscles to the bone tissue, thus enabling locomotion. It has been shown that tendons change their metabolism in response to mechanical forces and that, depending on the intensity of the mechanical stimulus, tendon fibroblasts secrete various proteins, such as collagen I and cyclooxygenase [1–5]. Although tendons are regarded as low metabolism tissue, under conditions of stress and during healing they can alter their metabolism significantly, leading to the secretion of various growth factors [3].

One of the key factors involved is the basic fibroblast growth factor-2 (FGF-2). This multifunctional, 146 amino acid polypeptide has been shown to affect the proliferation, chemotaxis, and differentiation of mesoderm-derived cells [6, 7]. Recent studies have identified it as a potential stimulator of angiogenesis, and this protein has been intensively studied in the wound healing processes of various animals [8–10]. Moreover, other proteins involved in the regulation of angiogenesis, such as vascular endothelial growth factor-A (VEGF-A), have been shown to play important roles in the remodeling of tendons and in their degenerative diseases [11]. Furthermore, VEGF-A has also been shown to stimulate endothelial cell proliferation and permeability [12]. Both of these factors may influence angiogenesis, the activity of which may be measured indirectly through the expression of CD34 antigen. This cell marker is characteristic of endothelial progenitor cells and of blood vessel endothelial cells [13]. Although the majority of these studies confirmed the impact of both FGF-2 and VEGF-A on tendon wound healing, only limited information is available concerning their significance in massaged rat tendons.

In view of the increasingly wide interest in active recreation (including running, biking, and aerobic exercise),
which in some situations is associated with excessive over-
load, trauma of anatomic structures of the locomotor system
(muscles, tendons, and ligaments) is diagnosed frequently.
A similar tendency can be seen in professional sports [14].

2.1. Animals and Experimental Design. The experiment was

conducted at the Animal Research section of the Department
of Pathomorphology, Medical University of Wroclaw, Poland.
During its course, all the animals were housed in identical
conditions. The study was conducted on 75 Buffalo strain rats,
all ten months old, randomly divided into three groups of 25
rats each. In the first group (PM, the premassaged group),
massage was performed five times a week for 3 weeks before
the running training. In the second group (M, the massaged
group), massage was applied five times per week for the whole
training experiment. The third group (C, the control group)
was subjected to running for 10 weeks without massage at all.
Rats of all three groups were subjected to running training on
an Exer-3R running track (Columbus Instruments, USA)
five days per week for ten weeks. The daily duration of
training began at 10 minutes on the first day and was increased
by 5 minutes every day, until it reached 30 minutes at the
end of the first week. Running was carried out at a speed of
0.3 m/s in the first week, and followed by an increased speed
of 0.5 m/s in the remaining period of the training.

2.2. Euthanasia and Sample Collection. The studies were

approved by Local Ethical Commission for the Animal
Experiments number 1 in Wroclaw (decision number 5/2011).
All possible steps were taken to avoid animal suffering
at each stage of the experiment. Rats of all three groups
were subjected to anesthesia using ketamine (10 mg/kg body
weight) and then sacrificed by decapitation. Tissue material
for the studies was sampled from 5 consecutive rats from
each experimental group on days 7, 21, 35, 49, and 70 of the
experiment. Tissue samples were collected from the middle
part of the tendon of the flexor digitorum longus in each
rear leg. Each resected tendon was divided into three parts:
(1) the first was fixed in 10% buffered formalin, dehydrated,
and embedded in paraffin, the second was stored in RNAlater
(Qiagen, Hilden, Germany), and the third was frozen in
liquid nitrogen and stored at −80°C.

Paraffin sections were stained with haematoxylin/eosin
(H&E) and assessed by a pathologist under a BX41 light
microscope (Olympus, Tokyo, Japan). The fragments stored
in RNAlater and fresh-frozen were utilized for molecular
studies.

2.3. Immunohistochemistry (IHC). Immunohistochemical
reactions were performed on 4 μm thick tendon sections
in an automated staining platform Autostainer Link48
(Dako, Glostrup, Denmark) to ensure constant reaction
conditions. In order to deparaffinise, rehydrate, and retrieve
the antigens, the sections were boiled in Target Retrieval
Solution High pH (9.0) buffer (Dako) using Pre-Treatment
Link Platform (Dako). Tendon sections were then washed in
TBS/0.05% Tween buffer followed by a 5 min incubation with
EnVision FLEX Peroxidase-Blocking Reagent to block the
activity of endogenous peroxidase. The sections were
then subsequently rinsed in TBS/0.05% Tween buffer
and incubated with primary antibodies (20 min at room temperature; RT) directed against CD34 (goat anti-rat, R&D Systems, Abington, UK) and VEGF-A (rabbit anti-rat, Antibodies-Online GmbH, Aachen, Germany). Sections were then washed in TBS/0.05% Tween followed by incubation (20 min, RT) with EnVision FLEX/horseradish peroxidase- (HRP-) conjugated secondary antibodies (Dako). In the next step the substrate for peroxidase, diaminobenzidine (Dako) was applied and the sections were incubated for 10 min at RT. Finally, the sections were counterstained with Mayer’s haematoxylin, dehydrated in alcohol (70%, 96%, and 99.8%) and xylene, and then mounted using SUB-X Mounting Medium (Dako).

2.4. RNA Extraction, cDNA Synthesis, and Real-Time PCR. Total RNA was isolated from 75 tendon fragments stored in RNA later using RNeasy Fibrous Mini Kit (Qiagen) in line with manufacturers’ recommended procedures. Reverse transcription reactions were processed using a High-Capacity cDNA Reverse Transcription Kit (Applied Biosystems, Carlsbad, CA, USA). The relative mRNA expression of VEGF-A, CD34, and FGF-2 was evaluated by real-time PCR using the 7500 Real-Time PCR System, primers, and probes of the TaqMan system (all from Life Technologies, Carlsbad, CA, USA). The primers and probes used in the reactions included Rn01511601_m1 for VEGF-A, Rn0341640_m1 for CD34, Rn00570809_m1 for FGF-2 and Rn99999991_s1 for GAPDH. Real-time PCR reactions were performed on 96-well plates (Life Technologies) at a set time and temperature, including polymerase activation at 50 °C for 2 minutes, preliminary denaturation at 94 °C for 10 minutes, denaturation at 94 °C for 15 s, and annealing of primers, probes, and synthesis at 60 °C for 1 min at 40 cycles. The results were standardized based on expression of GAPDH and the relative expression (RQ) of the studied genes was calculated using the ΔΔCt method [19]. The sample characterized by the lowest ΔΔCt was used as a calibrator in all the calculations.

2.5. SDS Page and Western Blot. The frozen tissue samples of 75 Buffalo strain rats tendons were homogenized in RIPA lysis buffer (50 mM Tris-Cl pH 8.0, 150 mM NaCl, 0.1% SDS, and 1% Igepal CA-630), 0.5% sodium deoxycholate, a cocktail of protease inhibitors, and 0.5 mM PMSF (all from Sigma, St. Louis, MI, USA). Protein concentration was measured using the BCA technique (Thermo Scientific, Waltham, MA, USA) and a NanoDrop 1000 spectrophotometer (Thermo Scientific). Tissue extracts were mixed with sample buffer (250 mM TRIS pH 6.8, 40% glycerol, 20% (v/v) β-mercaptoethanol, 100 mM DTT, 0.33 mg/mL bromophenol blue, and 8% SDS) and denatured for 10 min at 95 °C. Equal amounts of protein (20 μg per lane) were separated by electrophoresis, following Laemmli, in a 12% gel, using the Mini Protean 3 apparatus (BioRad, Hercules, CA, USA). Subsequently, the proteins were electrophoretically transferred to a PVDF membrane (Immobilon P, Millipore, Billerica, MA, USA) and nonspecific binding sites were blocked using 3% BSA in TBST buffer. The amount of the applied protein was controlled by staining the total protein on the membrane using Ponceau S (Sigma). The expression of VEGF-A was detected using specific monoclonal anti-VEGF-A antibody (Dako). Incubation was conducted for 18 h at 4 °C with gentle shaking in the solution of the antibody diluted 1:200 in 0.3% BSA, in 0.2% TBST (TBS and 20% Tween). After incubation the membrane was washed three times with 0.2% TBST buffer and incubated for 1 h with goat antimouse antibody conjugated with horseradish peroxidase (HRP) (1:2000, Jackson Immunoresearch, West Grove, PA, USA). The detection was conducted using a chemiluminescent substrate (LuminataTM Crescendo Western HRP Substrate; Millipore), and the results documented for exposure times ranging from 2 s to 30 min in a Chemi-Doc XRS Molecular Imager apparatus (Bio-Rad). The resulting bands were estimated by densitometric quantitative analysis of protein and normalized to GAPDH levels.

2.6. Statistical Analysis. Statistical analysis was performed using Prism 5.0 (GraphPad, La Jolla, CA, USA). The differences between the groups were tested using two-way ANOVA analysis of variance with the Bonferroni multiple-comparison test. Correlations between the examined markers were analyzed using Spearman's correlation test. In all analyses, the results were considered statistically significant when \( P < 0.05 \).

3. Results

3.1. Histological Findings. Histological examination revealed no changes of note in the structure of the analyzed tendon, regardless of the duration of the experiment or the study group. No areas of necrosis, calcification, or signs of collagen fiber degeneration or acute inflammation could be seen in any of the analyzed groups (Figures 1(a) and 1(b)). Furthermore, no mitotic figures in the analyzed tendons were noted. Analysis of IHC sections allowed the demonstration of VEGF-A immunoreactivity in the fibroblastic-like cells of peritendinous tissues (Figure 1(c)). In addition, CD34 expression was noted in blood vessel endothelium of the same sections (Figure 1(d)). Due to the low amounts of remaining tissue material for the IHC analysis, no reliable statistical analysis could be performed to compare the expression levels of these markers between the analyzed groups.

3.2. Analysis of VEGF-A, CD34, and FGF-2 mRNA Expression. Relative expression of the analyzed genes varied significantly with the experiment time and between particular study groups (Figure 2). The highest level of expression of VEGF-A mRNA was noted in the massaged group (M) and was significantly higher in relation to the control group (C) in all weeks of the study (\( P < 0.0001 \) for the first to fifth week, \( P < 0.0005 \) for the seventh week, and \( P < 0.005 \) for the tenth week). Similarly, the tendons of the animals in the M group also had significantly higher VEGF-A mRNA expression in comparison to those of the premassaged group (PM). Significant differences were noted for the first (\( P < 0.0001 \)), third (\( P < 0.0001 \)), seventh (\( P < 0.0005 \)), and tenth (\( P < 0.0005 \)) week. Unlike VEGF-A, the expression of CD34 was significantly higher only in the PM group compared to the non-massaged control group (C).

Correlations between the examined markers were analyzed using Spearman's correlation test. In all analyses, the results were considered statistically significant when \( P < 0.05 \).
Figure 1: H&E staining. A microphotograph of a rat tendon presenting nuclei of tendon cells (arrows) between parallel plates of collagen fibers. Note: no tissue lesions or inflammatory cells are visible in any of the sampled tendons, regardless of the duration or the experimental group (a). Blood vessels with erythrocytes in the lumen (indicated by arrows) are present in the resected rat tendons (b). IHC staining. In the peritendinous tissues VEGF-A expression was observed in fibroblastic-like cells (indicated by arrow) (c). CD34 expression was noted in blood vessel endothelium (indicated by arrow) (d).

0.05) weeks of the experiment. In the PM group, the VEGF-A mRNA expression was significantly higher, as compared to the C group, only in the fifth week of the experiment ($P < 0.05$) (Figure 2(a)). Differences were also noted in CD34 mRNA expression, the levels of which were highest in the M group, with significant increases in expression in the first ($P < 0.0005$), third ($P < 0.0001$), and fifth ($P < 0.005$) weeks of the experiment, as compared to the C group, and in the first ($P < 0.0005$) and third ($P < 0.005$) week, in comparison to the PM group. The mRNA expression of CD34 was significantly higher in the PM tendons, compared to the C group, in the fifth week of the studies ($P < 0.05$) (Figure 2(b)). The least pronounced differences were noted in the expression of FGF-2 mRNA, which was significantly higher in the M group in the third week of the study, as compared to the C and PM groups (both $P < 0.0001$) (Figure 2(c)). Taking the results together, the highest expression of all the analyzed genes in the M group developed in the third week of the study.

3.3. VEGF-A Protein Expression. As the most pronounced differences between the groups were detected in VEGF-A mRNA expression, it was decided to confirm our observations on the level of proteins. Using the anti-VEGF-A antibody, we visualized the monomeric form of VEGF-A (21 kDa) (Figure 3(a)). The 21 kDa VEGF-A monomeric form expression was significantly higher in the M group in the third and fifth weeks, than in the C (in both cases $P < 0.0001$) and PM groups ($P < 0.0001$ and $P < 0.0005$, resp.) (Figure 3(b)). The expression of VEGF-A mRNA correlated strongly with the optical density (OD) of the obtained bands ($r = 0.53$, $P < 0.0001$, Spearman’s correlation test) when the results were pooled from all the weeks of the study (Figure 3(c)). Moreover, as with VEGF-A mRNA expression, the highest VEGF-A protein expression was observed in the M group in the third week of the experiment.

4. Discussion

It has been shown that physical training can induce structural and functional alterations, not only in the skeletal muscles, but also in tendons [1, 16, 20–26]. These alterations reflect metabolic changes on a subcellular level in tendon tissue, such as increase in collagen synthesis [27–29]. Mechanical stimulation of the tendon during massage is thought to activate fibroblasts, which, through the increase in collagen synthesis, may promote tendon repair following trauma [30, 31]. Therefore, it can be argued that tendons’ reactions to mechanical stimuli include favorable alterations in their mechanical properties [32, 33]. Recently, Loghmani and Warden showed that instrument-assisted cross-fiber massage
Figure 2: Differentiated mRNA expression of VEGF-A (a), CD34 (b), and FGF-2 (c) in the massage (M), premassage (PM), and control (C) groups. Significant differences were noted between the M and C and between the PM and C groups. *P < 0.05, **P < 0.005, ***P < 0.0005, and ****P < 0.0001; Bonferroni multiple comparison test.

Our results demonstrate the most pronounced increases in the expression of VEGF-A, CD34, and FGF-2 genes and of VEGF-A protein, in the group of rats subjected to massage (group M) in the third week of the experiment. A slight increase in the expression of VEGF-A and CD34 in the group subjected to massage only prior to the training (group PM) was detected in the fifth week of the experiment. On the other hand, no significant alterations in the expression of the studied factors were seen in the group of rats that was subjected to the training alone, with no preceding or simultaneous massage (group C). This may point to significant adaptive processes in the group of animals that has been subjected to mechanical stimulation (massage) of tendons under load during the running training.

Multiple lines of evidence suggest that tendon fibroblasts subjected to cyclic stretching secrete higher amounts of TGF-β (transforming growth factor beta), PGE₂ (prostaglandin E₂), and LTB₄ (leukotriene B₄), resulting in increases in collagen type I levels and fibronectin production [3]. It can thus be assumed that elements of tendon tissue react to the nonspecific mechanical stimulus (massage) by activating the expression of several mediators, including FGF-2, which may initiate changes in the structure and mechanical properties of the tendon [34–36]. In several studies, FGF-2 was shown to stimulate the metabolic activity of fibroblasts, which are the main types of cells in a tendon and are responsible for the synthesis of extracellular matrix proteins. Therefore, the increased expression of FGF-2 observed in this study increases tissue perfusion and alters microvascular morphology during regeneration of injured knee ligaments [18]. So far, no data has been available concerning the effects of mechanical stimulation on angiogenesis processes in healthy tendons, which in turn may be of a key importance in the adaptive and regenerative processes of tendons.
as result of massage may point to the activation of tendon metabolism and the development of adaptive processes [37–39]. It seems that these adaptive processes may not be ascribed to the proliferation of fibroblasts, as no differences between analyzed groups upon histological examination were noted. However, we have recently shown that the massage of rat tendons modifies their structure by increasing the number of fibers with the smallest diameter (<100 nm), a fact which may indirectly corroborate the results obtained in this study [17].

Although a vast literature is available dealing with the transformation of mechanical stimuli acting on tissues into reactions at the cellular or molecular level [40–43], none of it explains the mechanism by which massage could stimulate angiogenesis in tendon tissue. Interestingly, in our study we observed an increased expression of VEGF-A and FGF-2 in the group of rats subjected to massage. VEGF-A is known to represent one of the most effective angiogenesis-stimulating agents in various types of tissues [12]. FGF-2, in turn, stimulates the metabolic activity of fibroblasts (the main cells in tendons, responsible for the synthesis of extracellular matrix proteins) and has also been shown to be a potent inducer of angiogenesis [8–10, 37–39]. The increase in the expression of both of these markers may explain the observed increase in the expression of CD34, a marker of endothelial progenitor cells and endothelial cells, which may indicate the development of new blood vessels, which could be visualized using the IHC method in this study [13]. Moreover, our results may partially explain the results obtained by Loghman and Warden [18], which showed that the massage of knee ligaments resulted in increased tissue perfusion and alteration in the microvascularity. The highest increase in mRNA expression of all the analyzed markers was observed in case of VEGF-A. These changes were also confirmed on the
protein level. Therefore it seems that massage may strongly stimulate the expression of these proteins, in addition to FGF-2, which in turn may strongly contribute to the adaptive processes of the tendon.

However, it should be stressed that animals utilized in these study were not perfused before sample collection. It is possible, that the observed increase in VEGF-A expression in tendons subjected to massage may be the result of increased number of myeloid-derived cells, for example, monocytes present in the blood vessels. FGF-2 was shown to potentiate leukocyte recruitment in a rat model of acute skin inflammation [44]. Similar effect may be hypothetically caused by massage via increase of its expression. FGF-2 recruited monocytes to the tendon tissues could stimulate angiogenesis, as in inflamed and hypoxic tissues in response to several cytokines [45, 46]. However, further research on the role of myeloid-derived cells in angiogenesis processes in the tendon is required to elucidate such hypothesis.

It should be noted that the deformation of the tendons during massage was executed with compression across the long axis of the tendon and was thus nonspecific, compared to the deformation developing during distension of the tendon following muscle contraction in the course of the physical activity. It is probably just for this reason that the observed alterations developed in the rats of the group subjected to massage, representing a reaction to the untypical factor acting on the tendon. On the other hand, the transient character of the alterations observed in the expression of VEGF-A, CD34, and FGF-2 (which reached their highest values in the third week of the experiment, to be followed by a gradual decrease until the end of the experiment) most probably reflect adaptive processes. This was particularly significant when compared to the unfavorable structural alterations noted in the tendons during the running training and involving a transient (developing between third and fifth weeks of training) decrease in the number, diameter, and cross-sectional area of the tendon-forming collagen fibers [16]. On this basis, the increase in angiogenesis and fibroblast activity induced by mechanical stimulation (massage) of a tendon may be expected to prevent the transient tendency for its structure to weaken. This may decrease the development of lesions within tendons during their long-term overload in the course of running.

5. Conclusions

The obtained results may point indirectly to a beneficial effect of massage conducted during long-term intense physical effort on tissue metabolism in the tendon. Moreover, the increased metabolism in the tendons may exert a protective effect in situations where there is an increased risk of tendon damage from unfavorable structural alterations developing during long-term high-intensity physical effort, such as running. However, further studies on the molecular and structural levels are required to fully clarify the mechanisms behind the changes developing in tendon tissue subjected to massage in the course of strenuous physical effort.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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