Journal of Exercise Science & Fitness 16 (2018) 112–117

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Effect of deep oscillation as a recovery method after fatiguing soccer training: A randomized cross-over study

Simon von Stengel*, Marc Teschler, Anja Weissenfels, Sebastian Willert, Wolfgang Kemmler

Institute of Medical Physics, Friedrich-Alexander University of Erlangen-Nürnberg, Henkestraße 91, 91052, Erlangen, Germany

ARTICLE INFO

Article history:
Received 21 June 2018
Received in revised form
10 October 2018
Accepted 11 October 2018
Available online 16 October 2018

Keywords:
Soccer
Football
Regeneration
Deep oscillation
Electrical therapy

ABSTRACT

Background/Objective: In soccer the recovery time between matches is often not long enough for complete restoration. Insufficient recovery can result in reduced performance and a higher risk of injuries. The purpose of this study was to evaluate the potential of Deep Oscillation (DO) as a recovery method.
Methods: In a randomized crossover study including 8 male soccer players (22 ± 3.3 years) the following parameters were evaluated directly before and 48 h after a fatiguing soccer-specific exercise: Maximum isokinetic strength of the leg and hip extensors and flexors (Con-Trex® Leg Press, Physiomed, Germany), rating of perceived exertion (RPE) during isokinetic testing (Borg scale 6–20), creatine kinase (CK) serum levels and Delayed Onset Muscle Soreness (DOMS; visual analogue scale 1–10). By random allocation, half of the group performed a DO self-treatment twice daily (4 applications of 15min each), whilst the other half received no intervention. 4 weeks later a cross-over was conducted. Two-way repeated measures analysis of variance was used to compare treatment versus control.
Results: A significant treatment effect was observed for maximum leg flexion strength (p = 0.03; DO: 125 ± 206 N vs. CG: −115 ± 194; p = 0.03) and for RPE (DO: −0.13 ± 0.64; vs. CG: +1.13 ± 1.36; p = 0.03). There was a trend to better recovery for maximum leg extension strength (DO: −31 ± 165 N vs. CG: −138 ± 212; p = 0.028), CK values (DO: 72 ± 331 U/ml vs. CG: 535 ± 797 U/ml; p = 0.15) and DOMS (DO: 3.4 ± 1.5 vs. CG: 4.1 ± 2.6; p = 0.49).
Conclusion: In the present study we found significant effects of DO on maximum leg flexion strength and perceived rate of exertion. Other variables showed a consistent trend in favour of DO compared with the control without significance. DO seems to be a promising method to accelerate the time-course of peripheral recovery of muscle which should be addressed in larger studies in future.
Trial registration: ClinicalTrials.gov; NCT03411278, 18.01.2018 (during the study).

Introduction

Soccer is a high-intensity, intermittent-sprint sport that places very high demands on the different components of motor performance.[1] The high muscular strain in matches and training leads to a depletion of energy stores, an accumulation of metabolic by-products, muscular soreness and finally results in peripheral and central fatigue.[2] In soccer, breaks between matches are often short, consequently the time between matches might not be sufficient for adequate regeneration.[3] A systematic review shows that a post-match period of 72 h is not long enough for complete recovery particularly with respect to muscle damage.[4]

Regarding this insuffcent recovery time, it can be assumed that an enhancement of regeneration would result in improved performance in matches and training. For this reason, a wide range of recovery modalities are currently being discussed as integral parts of the training programs of players in order to enhance between-training session recovery.[3]

Recovery modalities include post-exercise cooling,[5] cold water immersion or contrast water therapy,[6] compression clothing,[7] whole-body vibration,[8] massage[9] or lymphatic drainage[10–12] as a

* Corresponding author.
E-mail addresses: simon.von.stengel@imp.uni-erlangen.de (S. von Stengel), marc.teschler@imp.uni-erlangen.de (M. Teschler), anja.weissenfels@imp.uni-erlangen.de (A. Weissenfels), sebastian.willert@imp.uni-erlangen.de (S. Willert), wolfgang.kemmler@imp.uni-erlangen.de (W. Kemmler).

https://doi.org/10.1016/j.jesf.2018.10.004
1728-869X/

special massage form. Massage forms are recognized measures for promoting regeneration.[13] It has been shown that massage initiated immediately after exercise and massage delayed by 48 h were both effective in reducing muscle oedema and decreasing the number of damaged muscle fibres.[14] However, due to the high personnel requirements, massage treatments in soccer are usually limited to the treatment of complaints and injuries and are rarely used to consistently promote regeneration. In this context, deep oscillation (DO) might be an attractive option since it can easily be carried out by players as self-treatment.

In deep oscillation, an alternating electrostatic field is built up between the tissue of the patient and the hand of the therapist or a hand applicator. When moving over the patient's skin electrostatic forces alternately pull and release the tissue, which results in a deep resonance vibration that penetrates the patient's tissue over all tissue components (skin, connective tissue, subcutaneous fat, fasciae, muscles, blood and lymph vessels).[15]

The effect of deep oscillation has been investigated for various indications. In randomized controlled trials, DO was reported to be effective in reducing oedema and hematoma,[16,17] reducing inflammation[15] and pain,[16–18] or increasing healing of sports traumata.[16] In one study DO showed a relaxing effect on the hamstrings muscles, which was expressed in an extension of the range of movement directly after the application.[19] DO could be effective for promoting recovery. Studies have showed that the interaction between mechanical and electrostatic stimuli in DO improves lymph flow,[20] increases blood flow and perfusion,[12] modulates inflammation processes[15] and positively impacts mechanical properties of muscles.[19]

To our best knowledge, there is only one study which determined the effect of DO on post-exercise recovery in mixed martial arts athletes. In this study, which focused on the forearm muscles, DO was effective for recovery in the first phase of post-exercise (20min) only. It increased muscular strength while reducing pain level, blood lactate and muscle tension.[12] After 24 and 48 h, there was no positive influence regarding neuromuscular performance. In this study, however, post-exercise, a 20-min treatment with DO took place only once.

The purpose of the present study was to evaluate the effects of DO as a recovery method for soccer players. We hypothesized that DO self-treatment of 15 min twice daily (4 treatments) provides significant positive effects on maximum strength, CK levels and muscle soreness 48 h after fatiguing exercise compared with a non-intervention control condition.

Methods

Trial design

A randomized, cross-over, repeated measures design was used to evaluate the effects of DO on recovery. Baseline measurements were performed immediately before a soccer training session to fatigue. The same measurements were carried out 48 h later again. By random allocation, half of the group performed a DO self-treatment twice daily (4 applications) for 15 min each, whereas the other participants received no intervention.

4 weeks later in a cross-over design the same procedure was conducted again, with the participants who received no treatment during the first study phase conducting the DO intervention and vice versa. Fig. 1 illustrates the study design.

The Institute of Medical Physics (IMP), Friedrich Alexander-University Erlangen-Nürnberg (FAU), Germany initiated the study that was conducted from December 2017 to February 2018. The study was approved by the ethics committee of the FAU (Ethikantrag No. 374_15B). The study complied with the Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects". After detailed information, all participants gave written informed consent. The study was fully registerd under clinical trials.gov (NCT03411278).

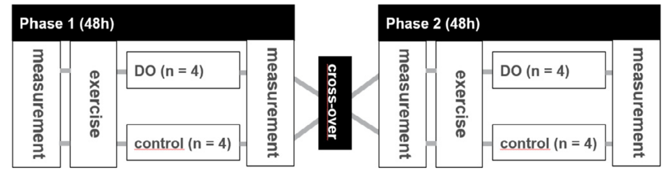

Fig. 1. Study design: baseline measurement, directly followed by a fatiguing exercise. DO intervention versus control and follow-up measurements after 48 h. Repetition of the protocol after 4 weeks in a cross-over design.

Participants

Participants were recruited from a German soccer team of the 5th division (of the 10 soccer divisions in Germany (Landesliga)). Inclusion criterion was age between 18 and 30 years. Exclusion criteria were any kind of injury or illness. The study included eight male participants of 19–27 years of age (22 ± 3y). A sample size of 8 participants per condition enables us to detect a difference of $5 \pm 3\%$ with 90% power ($\alpha = 0.05$) (*t*-test based sample size calculation). The participants played soccer three to four times a week (two to three times training/w, one match/w.; ca. 250min/w.). Participants were randomly assigned to DO treatment or control by envelop method after the baseline measurement. Neither participants nor researchers knew the allocation beforehand. After the group allocation, the head of the study enrolled participants and carefully instructed them about the significance of their status including corresponding dos and don'ts.

Intervention

Fatiguing exercise protocol

Study participants were asked to refrain from vigorous physical activity (apart from the fatiguing exercise sessions in each study phase) starting 48 h before the baseline testing until the follow-up measurements 48 h post-exercise. Also, participants were instructed to keep other lifestyle habits constant in both study phases (e.g. food consumption and sleep modalities) and to avoid alcohol.

The fatiguing exercise protocol was defined as a soccer-specific conditioning program (90 min) with specific focus on agility, sprint and strength parameters. The session started with a common warm-up and activation program for 15min including movement patterns from sprinter ABC, core stability and (functional) movement prep exercises. After warm-up an agility/change of direction (COD) speed exercise was carried out. Each player conducted 6 of the following rounds with rests of 60s between rounds. Immediately after 5 single-legged low hurdle jumps (each round with one leg, left/right leg alternating) the players had to perform a 5×5 m sprint with four 45° turns touching a pole before scoring. Subsequently, subjects conducted 6 series of 5 two-legged jumps over 60 cm high hurdles spaced apart 45 cm with a rest of 30 s after each set of 5 jumps and 2 min after 3 series. In series 4, 5 and 6, a 5 kg medicine ball was used as extra weight focussing on a slow eccentric phase. After that, focus was put on sprints with resistance. In pairs, subjects performed 10 sprints for 10 s with physical resistance created by one of the athletes holding power tube which was wrapped around the other person's hips. After each turn the athletes changed. Finally, after two-legged jumps over a 50 cm hurdle two players competed in 15 m sprints on an ascending area (slope 20%). Each subject conducted 6 repetitions with changing competitors. The session ended with a 30 min standard training game to include some soccer-specific tactical and technical elements.

Deep oscillation intervention

Immediately after baseline measurements, participants were individually instructed on how to carry out the DO self treatment with the "personal" device (Physiomed, Schnaittach, Germany; U.S. patent 7,343,203 B2). The device produces an alternating electrostatic field, which results in a low-frequency vibration penetrating the tissue to a depth of 8 cm through all tissue layers.[15] The field was pulsed at a modulated frequency betueen 28–85 Hz. An applicator with a diameter of 9.5 cm was used. For self-treatment, each volunteer was given a device to take home. The treatment was to be carried out at home in the morning and evening for 15 min in a supine position. In accordance with the technique of classical manual lymphatic drainage, stroking and circular movements in the upper and lower leg and the inguinal area took place in a fixed order.

Measurements

Measurements were carried out in the Institute of Medical Physics, University Erlangen, Germany. Outcome assessors and research assistants were blinded i.e. not informed with respect to the group status of the participant and were not allowed to ask. Baseline and follow-up assessment of the participant were conducted at the same time of the day (±1 h) in the same order by the same assessors.

Primary study outcome

Changes of maximum isokinetic strength of the leg and hip extensors and flexors as determined by an isokinetic leg press at baseline and after the intervention period.

Secondary study outcomes

Rating of perceived exertion (RPE) during isokinetic testing, creatine kinase (CK) serum levels and Delayed Onset Muscle Soreness (DOMS). Height was determined with a Harpender stadiometer (Holtain Ltd., Crymmych, Wales). Body mass, lean body mass and body fat were tested via segmental multi-frequency bioelectrical impedance analysis (Inbody230, Biospace, Seoul, Korea), which measures the impedance at both hands and feet using an eight-electrode technique. The anthropometric measurements were carried out at baseline only.

Maximum isokinetic strength of the leg and hip extensors and flexors, which represent the primary study outcome, was tested using a Con-Trex isokinetic leg press (Physiomed, Schnaittach, Germany). Bilateral leg and hip extension and flexion were performed in a sitting position. The subjects were fixed on the device with two chest belts. The range of movement was adjusted so that the knee flexion angle during movement ranged between 30 and 90°. The feet were fixed with straps on the sliding footplates. The standard default setting of 0.5 m/s was used. After familiarization with the movement pattern and standardized warm-up (10 reps with ≈50% 1RM with a 2 min break after the warm-up), participants were asked to conduct five repetitions with maximum voluntary effort. The peak forces within the five repetitions were recorded for flexion and extension. Participants conducted two trials intermitted by two minutes of rest. We consistently included the higher value of both trials for extension and flexion in the data analysis. Applying this approach, reliability for the maximum leg press test (Test-Retest-Reliability; Intra Class Correlation) was 0.88 (95%-CI: 0.82–0.93) in a previous study.[21]

Rating of perceived exertion (RPE) was obtained immediately after the maximum strength test using the Borg 20-point scale.

Blood was sampled under non-fasting condition from an antecubital vein. Creatine kinase (CK) was analysed out of the serum using the Beckmann Coulter Inc. device (Brea, USA).

Delayed Onset Muscle Soreness (DOMS), defined as the sensation of a dull, aching pain of the thigh muscles during movement, was self reported using a 100-mm visual analogue scale. The scale ranged from "no soreness" (0) to "severe soreness" (100) The participants were asked to mark their soreness when going downstairs a staircase 24 and 48 h after training.

Statistical analysis

Normality of the dependent variables was checked using graphical (QQ- and box-plots) and statistical (Shapiro-Wilkes-Test) procedures. A two-way (group-time) analysis of variance (ANOVA) for repeated measures was performed to test significance between groups for maximum leg extension and flexion strength and CK values. Following a significant F-test, post hoc Bonferroni multiple comparisons analysis was applied. One-way ANOVA was used to analyze DOMS values. Data are presented as means ± standard deviations (s) unless otherwise stated.

All statistical analyses were conducted using SPSS version 25 (SPSS Inc., Chicago, IL). All tests were 2-tailed, significance was set at $P < 0.05$. Effect sizes (d) were computed to determine the magnitude of an effect between the groups using Cohen's d. Values of $d \leq 0.2$ were considered small effects, $0.2 \leq d < 0.8$ moderate, and $d \geq 0.8$ large.

Results

Table 1 shows the characteristics of the study participants. Table 2 gives the results of the maximum strength measurements. Repeated measures AVOVA revealed no significant treatment or treatment × time interaction for maximum hip and leg extension strength ($p = 0.28$) and the effect size was moderate. On the other hand, a significant treatment or treatment × time interaction was observed for maximum leg flexion strength ($p = 0.03$) at a high effect size. There was also a treatment or treatment × time interaction with regard to the RPE during the isokinetic maximum leg strength tests ($p = 0.03$). While the DO condition experienced the same effort in the follow-up test, the control condition found the follow up test to be more strenuous.

With regard to CK values (Table 2), there was a tendency to an improved recovery in the DO condition compared with control, but repeated measures AVOVA revealed no significant treatment or treatment × time interaction ($p = 0.15$). There was only a small difference between the conditions with respect to DOMS values which were far from being significant on day one (VAS: −0.87; $p = 0.362$) and day two (VAS: −0.75; $p = 0.49$)(Table 3).

Discussion

Adequate regeneration is crucial for achieving maximum performance in soccer matches and for optimum performance

Table 1
Anthropometric characteristics (mean value ± standard deviation) of the participants (n = 8).

Characteristics	Mean ± SD
Age (y)	22 ± 3.3
Weight (kg)	77.4 ± 5.4
Height (cm)	180.9 ± 7.4
Percentage body fat (%)	13.4 ± 3.9

Table 2
Maximum leg extension and flexion strength, rate of perceived exertion (RPE) during the isokinetic maximum leg strength test, creatine kinase values in the isokinetic legpress (LP) in the CG and DO condition at baseline and follow up and intragroup changes. Mean between-group differences with 95% confidence interval, p-value and effect size.

LP ext. strength (N)	CG	DO	MV (CI)	P	ES
pre	3493 ± 428	3431 ± 476			
post 48 h	3355 ± 330	3400 ± 441			
diff	−138 ± 212	−31 ± 165	−106 (−310 to 97)	0.283	0.56
LP flex. strength (N)					
pre	1981 ± 519	1810 ± 713			
post 48 h	1866 ± 500	1935 ± 773			
diff	−115 ± 194	125 ± 206	−240 (−454 to −97)	0,031	1.19
RPE (Borg)					
pre	16.9 ± 0.83	17.8 ± 1.16			
post 48 h	18.0 ± 1.2	17.6 ± 0.92			
diff	1.13 ± 1.36	−0.13 ± 0.64	−1.0 (−0.07 to −2.43)	0.034	0.94
CK (U/ml)	CG	DO	MV (CI)	P	ES
pre	550 ± 466	438 ± 258			
post 48 h	1085 ± 1017	510 ± 488			
diff	535 ± 797	72 ± 331	−463 (−223 to 1148)	0.152	0.76

Table 3
DOMS values in the CG and DO condition 24 and 48 h post-exercise. Mean between-group differences, p-value and effect size.

DOMS	CG	DO	diff	P	ES
1 day post	5.75 ± 1.67	4.88 ± 2.03	−0.87	0.362	0.47
2 day post	4.13 ± 2,59	3.38 ± 1.52	−0.75	0.49	0.35

development in the systematic training process. We investigated deep oscillation (DO) as a measure to promote regeneration, hypothesizing that DO leads to accelerated recovery with a positive effect on maximum strength, perceived exertion rating, creatin kinase concentration (CK) values and muscular soreness compared with control condition.

There was a significant difference between the conditions for maximum leg flexion strength. In line with the maximum flexion strength values, there was also a significant group difference with regard to the rated perceived exertion (RPE). The fact that the maximum force tests at follow-up were considered more strenuous by the control group indicates incomplete regeneration, unlike the DO group. However, with respect to maximum leg extension strength, the difference in favour of the DO group did not reach the level of statistical significance. The study cannot provide an explanation for the fact that an effect of DO could be determined for maximum leg flexion strength, but not for leg extension. Looking at the literature, one plausible explanation might be the shorter (48 h) recovery period for quadriceps strength compared with hamstring strength.[2] Thus, it could be assumed that quadricep strength was restored after 48 h with or without regeneration-enhancing measures.

There was also a positive trend towards more pronounced CK reductions in the DO condition. While the control group had values twice as high as baseline 48 h after exercise, the follow-up values in the DO group were within the range of the pre-exercise level (Table 2). The fact that these large differences did not reach statistical level of significance is related to the high standard deviations, in part related to the large inter-individual and intra-individual variation among individuals, which is typical for this variable.[22–24] Power analysis was based on maximum leg extension strength. A power analysis for CK, which takes into account the higher standard deviations of CK, would have led to a bigger sample size. So the study was underpowered for the secondary endpoint CK. The relatively high baseline values of CK might have been due to a soccer match played 52 h before the baseline measurements.

Finally, in terms of muscle soreness there was only a slight positive trend in favour of the DO group, with lower values of perceived muscle pain. However, this difference between the groups was far from statistically significant.

Taken together, there was a general trend in favour of the DO condition compared with the control condition for all variables. For maximum leg flexion strength and for RPE the differences reached statistical significance. It can be hypothesized that the small sample size could have resulted in a beta error, which means that the statistical test shows no significant difference though a true difference does in fact exist (false negative results). The high standard deviation might have prevented significance especially for CK. Accordingly, further studies with a larger sample size to check the hypothesis would be desirable for the future.

Studies indicate a heterochronism in recovery i.e. different systems require different periods of time to recover.[3] A meta-analysis shows that a period of 72 h post-match is not long enough to completely recover particularly with respect to muscle damage.[4] Since the recovery time between soccer matches or intense exercise training is often shorter than 72 h, measures that shorten the regeneration process are of great importance in competitive soccer. Muscle massage[9] or manual lymphatic drainage[10–12] are used especially to accelerate the time course of peripheral recovery of muscles. Lymphatic drainage promotes the lymph flow velocity up to 8-fold of resting condition[25] and increases the amount of fluid removed from peripheral tissues per time unit, resulting in both an oedema-reducing effect and increased clearance of metabolic waste products from the extracellular space.[26]

Like lymphatic drainage, DO also focuses on the lymphatic system. In randomized controlled studies it showed excellent results in reducing oedema and hematoma.[16,17] One study reported that the effect of classical manual lymphatic drainage on pain and swelling is enhanced when performed under DO.[17] DO demonstrated to increase blood circulation and perfusion.[12] Further, DO showed an anti-inflammatory effect. In a human skin model IL-8 concentration and dilated vessles were reduced, demonstrating the antinflammatory effect of DO, which can be considered positive with regard to regeneration.[15] In one study, DO also showed a positive effect on the extensibility of hamstring muscles, indicating an effect on viscoelastic properties of muscles and fasciae, a result which also might be relevant for regeneration and injury prevention.[19]

Apart from our trial, to our best knowledge, there is only one other study which determined the effect of a single DO application on regeneration after a fatiguing exercise. This study assessed the effect of the different forms of lymphatic drainage, including manual lymphatic drainage, electro-stimulation (Bodyflow) and DO on post-exercise regeneration of the forearm muscles of martial arts athletes. In the study DO increased vein blood flow velocity in the same way as the other two interventions, but had a more pronounced effect on perfusion.[12] The perfusion units measured by ultrasound Doppler flowmeter were 41.7 PU after a 20min session manual lymphatic drainage, 23.6 PU after electrical stimulation and 108 PU after a 20min DO session, compared with control rest flow of 11.8 PU.[12] In the first phase of recovery (20min) there was a significant positive effect of all three interventions on maximum forearm strength, lactate level and muscle tension. However, apart from an increased pain threshold in DO and manual lymphatic drainage group, no significant effects occurred after 24 and 48 h. In the light of these data, it can be hypothesized that a single DO treatment may not be sufficient to significantly influence the long-term recovery in the days following fatigue.

One big advantage of DO compared with conventional massage techniques is the possibility to carry out DO treatment as self-treatment, which allows a higher treatment frequency. Soccer teams consist of a pool of at least 20 players and due to a lack of therapeutical staff and/or time, massage techniques are rarely used in non- or semi-professional soccer teams for regeneration purpose only. Unlike manual massage techniques performed by physiotherapists, DO self-treatment is a time and personnel efficient method, which can be used by players at home.

The study has some limitations: 1. It was a relatively small study with a sample size of eight cases per condition. The limited power of the study results in a high risk of a beta error. 2. The measurements were carried out directly before the fatiguing training and 48 h after only. Quantifying fatigue immediately after training and 24 h and 72 h afterwards would have provided more detailed insights into the time course of the restitution of the various endpoints with their heterochronism in restitution and the possible influence of DO. Just one follow-up measurement was carried out for economic reasons. Using this procedure, we chose the follow-up time of 48 h, because at this time point the recovery for the leg bending force, CK level and DOMS is still uncomplete.[4] A shorter time window (24 h) would have reduced the potential effect of the intervention because of lower numbers of treatment and time. Using a longer period (72 h) the recovery would have already been (almost) complete even without regeneration accelerating measures. DOMS was recorded post exercise only. 3. Not a real football match was used as intervention for inducing fatigue. The reason behind this decision was the high importance for standardization of the loading to generate identical fatigue in both settings. In two football matches, depending on different factors such as time of play, position, tactics and opponents, the possibilities for standardization are limited. 4. The asessements were no football specific physical performance measurements such as sprint measures or change of direction ability. However, we think that the study endpoints were suitable to detect influence of local treatment of leg muscles by means of deep oscillation on peripheral muscle fatigue.

Altogether, DO could be a method to accelerate the time course of peripheral recovery of the muscle. In the present study, the first study to focus on the effect of DO on muscular recovery, we determined significant effects on maximum leg flexion strength and perceived rate of exertion. However, other variables showed just a trend in favour to DO compared with control condition without significance. So further studies are needed to evaluate the effect of DO in the regeneration process. These studies should also address the dose-response effect of DO, as there is a lack of knowledge about the optimum application time and frequency. Furthermore, the use of DO in combination with other recovery strategies would be an area worth investigating.

Conflicts of interest

The authors declare that they have no conflicting interests.

Funding/support

The paper presents independent research at the Institute of Medical Physics, Friedrich-Alexander University of Erlangen-Nürnberg, Germany without funding.

Acknowledgement

We are grateful for the support of Physiomed, Laipersdorf, Germany, who supplied 4 DEEP OSCILLATION Personal devices for the duration of the study.

References

1. Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci*. 2003;21: 519–528.
2. Thomas K, Dent J, Howatson G, Goodall S. Etiology and recovery of neuromuscular fatigue after simulated soccer match play. *Med Sci Sports Exerc*. 2017;49:955–964.
3. Barnett A. Using recovery modalities between training sessions in elite athletes. does it help? *Sports Med*. 2006;36:781–796.
4. Silva JR, Rumpf MC, Hertzog M, et al. Acute and residual soccer match-related fatigue: a systematic review and meta-analysis. *Sports Med*. 2018;48:539–583.
5. Poppendieck W, Faude O, Wegmann M, Meyer T. Cooling and performance recovery of trained athletes. A meta-analytical review. *Int J Sports Physiol Perform*. 2013;8:227–242.
6. Higgins TR, Greene DA, Baker MK. Effects of cold water immersion and contrast water therapy for recovery from team sport: a systematic review and meta-analysis. *J Strength Condit Res*. 2017;31:1443–1460.
7. Born DP, Sperlich B, Holmberg HC. Bringing light into the dark: effects of compression clothing on performance and recovery. *Int J Sports Physiol Perform*. 2013;8:4–18.
8. Timon R, Tejero J, Brazo-Sayavera J, Crespo C, Olcina G. Effects of whole-body vibration after eccentric exercise on muscle soreness and muscle strength recovery. *J Phys Ther Sci*. 2016;28:1781–1785.
9. Poppendieck W, Wegmann M, Ferrauti A, Kellmann M, Pfeiffer M, Meyer T. Massage and performance recovery: a meta-analytical review. *Sports Med*. 2016;46:183–204.
10. Bakar Y, Coknaz H, Karli U, Semsek O, Serin E, Pala OO. Effect of manual lymph drainage on removal of blood lactate after submaximal exercise. *J Phys Ther Sci*. 2015;27:3387–3391.
11. Behringer M, Jedlicka D, McCourt M, Ring M, Mester J. Effects of lymphatic drainage and local cryo exposition regeneration after high-intensive exercises. *Muscles, ligaments and tendons journal*. 2016;6:228–235.
12. Zebrowska A, Trybulski R, Roczniok R, Marcol W. Effect of physical methods of lymphatic drainage on postexercise recovery of mixed martial arts athletes. *Clin J Sport Med*. 2017 Aug 16. https://doi.org/10.1097/JSM.0000000000000485 [Epub ahead of print].
13. Best TM, Crawford SK. Massage and postexercise recovery: the science is emerging. *Br J Sports Med*. 2017;51:1386–1387.
14. Haas C, Butterfield TA, Abshire S, et al. Massage timing affects postexercise muscle recovery and inflammation in a rabbit model. *Med Sci Sports Exerc*. 2013;45:1105–1112.
15. Boisnic S. BMC: anti-inflammatory and draining effect of the Deep Oscillation device tested clinically and on a model of human skin maintained in survival condition. *Eur J Dermatol*. 2013;1:59–63.
16. Aliyev RM. Better functional results of conservative treatment in fresh lateral ligament injuries of the ankle with additional deep oscillation. *Phys Med Rehab Kuror*. 2012;22:9–15.
17. Jahr S, Reisshauer A. Effect of treatment with low-intensity and extremely low-frequency electrostatic fields (Deep Oscillation) on breast tissue and pain in patients with secondary breast lymphoedema. *J Rehabil Med*. 2008;8:645–650.
18. Reinhold J, Korkina L, Schaper K, Krummenauer F. Randomisierte Pilotstudie zur Quantifizierung des patientenseitigen Nutzens der Beeinflussung primärer Wundheilungsprozesse durch Tiefenoszillation (English title: randomised Pilot Study for Quantification of Benefit from the Patient's Point of View of Deep Oscillation Treatment in Primary Wound Healing). *Z für Orthop Unfallchirurgie*. 2014;3:260–264.
19. Hinman MR, Perry E, Robbins K, Viertel L. Comparative effect of ultrasound and DEEP OSCILLATION® on the extensibility of hamstring muscles. *Journal of Athletics Medicine*. 2013;1:45–55.
20. Aliyev R. Klinische Wirksamkeit des Therapieverfahrens Tiefenoszillation bei Sportverletzungen (English title: clinical effects of the therapy method deep oscillation in treatment of sports injuries). *Sportverletz Sportschaden*. 2009;23:

1–4.
21. Wittke A, von Stengel S, Hettchen M, et al. Protein supplementation to augment the effects of high intensity resistance training in untrained middle-aged males: the randomized controlled PUSH trial. *BioMed Res Int*. 2017. https://doi.org/10.1155/2017/3619398.
22. Baird MF, Graham SM, Baker JS, Bickerstaff GF. Creatine-kinase- and exercise-related muscle damage implications for muscle performance and recovery. *Journal of nutrition and metabolism*. 2012. https://doi.org/10.1155/2012/960363.
23. Brancaccio P, Maffulli N, Limongelli FM. Creatine kinase monitoring in sport medicine. *Br Med Bull*. 2007;81–82:209–230.
24. Russell M, Northeast J, Atkinson G, et al. Between-match variability of peak power output and creatine kinase responses to soccer match-play. *J Strength Condit Res*. 2015;29:2079–2085.
25. Schillinger A, Koenig D, Haefele C, et al. Effect of manual lymph drainage on the course of serum levels of muscle enzymes after treadmill exercise. *Am J Phys Med Rehabil*. 2006;85:516–520.
26. Lesho EP. An overview of osteopathic medicine. *Arch Fam Med*. 1999;8:477–484.