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Deep heating therapy via microwave diathermy relieves pain and improves physical function in patients with knee osteoarthritis: a double-blind randomized clinical trial

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***Background*. Deep heating therapy (DHT) has shown to improve pain and function in patients with knee osteoarthritis (OA) in the short term. Benefits of superficial heating therapy (SHT) are controversial. Long-term effects of both heating modalities have not yet been investigated.**
***Aim*. To compare the effects of DHT and SHT in patients with symptomatic knee OA, and to determine the long-term effects of heat therapy.**
***Design*. Double-blind randomized clinical trial.**
***Setting*. Outpatient clinic of the Department of Geriatrics, Gerontology and Physiatrics, University Hospital.**
***Population*. Fifty-four patients with radiologically established diagnosis of moderate knee OA (Kellgren-Lawrence grade II or III) and pain lasting for at least three weeks.**
***Methods*. DHT: local microwave diathermy (three 30-min sessions a week for four weeks); SHT: application of hot packs (three 30-min sessions a week for four weeks). Primary outcome measure: Western Ontario and McMaster Universities (WOMAC) index for the assessment of joint pain, stiffness and physical function limitations. Secondary outcome measures: British Medical Research Council (BMRC) rating scale for the evaluation of muscle strength, and a visual analogue scale (VAS) for pain assessment. Follow up: 24 weeks for all outcome measures; 12 months for the primary outcome.**
***Results*. Intention-to-treat analyses showed a treatment effect in favor of DHT for all outcome measures. No clinically relevant changes were observed in the SHT group. Benefits of DHT were maintained over 12 months of follow-up.**
***Conclusions*. DHT via localized microwave diathermy improves pain, muscle strength and physical function in patients affected by knee OA, with benefits maintained over the long term. No clinically relevant improvements were observed in patients subjected to SHT.**
***Clinical Rehabilitation Impact*. DHT via microwave diathermy delivered three times a week for four weeks significantly improves pain and function in patients affected by moderate knee OA, with benefits retained for at least 12 months. No clinically relevant changes are observed in knee OA patients treated with SHT.**

KEY WORDS: Hyperthermia, induced - Knee - Pain - Randomized controlled trials as topic.

Osteoarthritis (OA) is the most common form of arthritis and a major cause of disability in Western countries.[1] The knee is among the most frequently affected joints.[2] The prevalence of knee OA rises steadily with advancing age, and is higher in women than in men.[3] Radiographic signs of knee OA are found in the majority of 65-year-old persons and in about 80% of those aged 75 years or older.[2] Symptomatic knee OA occurs in 10% and 13% of men and women over the age of 60,

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respectively.[4] Furthermore, due to the progressive aging of the population and the escalating prevalence of obesity, it is projected that the number of people affected by knee OA will dramatically rise in the next decades.[5, 6] Pain and functional limitations due to knee OA significantly impact quality of life and impose a substantial burden of healthcare expenditures.[7]

Despite the individual and societal burden associated with OA, no disease-modifying drugs are yet available for this condition. Hence, the main purposes of treatments for knee OA are to lessen joint pain and stiffness, maintain and improve joint mobility, reduce physical disability and ameliorate quality of life.[8] Knee joint arthroplasty is effective in relieving symptoms and improving function and quality of life in patients with knee OA.[9] However, an initial course of conservative treatment based on the combination of physiotherapy and drugs, is generally recommended.[8]

Heat therapy has long been used in the management of knee OA. Heat can be administered by a variety of techniques, including ultrasounds, shortwave or microwave diathermy, local application of hot packs or immersion in warm water and wax baths.[8] The resulting hyperthermia is believed to act by increasing local blood flow, which accelerates metabolic processes and toxin removal, thereby facilitating tissue repair and promoting pain relief.[10] In a recent study, 4-week localized microwave diathermy has shown to improve pain and physical function in patients with symptomatic knee OA, with benefits retained over a 12-week follow-up.[11] Conversely, Akyiol *et al.*[12] reported no added benefits of short-wave diathermy in patients affected by knee OA undergoing isokinetic exercise training. Furthermore, it is currently unknown if improvements produced by deep heating therapy (DHT) are maintained over the long term. What is more, the efficacy of superficial heating therapy (SHT) is mostly anecdotal and, to our knowledge, no randomized clinical trials have yet been performed to determine the effects of this treatment modality in comparison to DHT in knee OA. Hence, the purpose of the present study was to compare the effects of DHT and SHT, induced via microwave diathermy and hot packs, respectively, on pain and function in patients with symptomatic knee OA. A 12-month follow-up was performed in order to determine the long-term effects of treatments.

Materials and methods

Participants

The study was designed as a double-blind randomized trial. Participants were recruited ~~from~~ among patients referred for knee pain to the outpatient clinic of the Department of Gerontology, Geriatrics and Physiatrics, University Hospital "Agostino Gemelli" (Catholic University of the Sacred Heart, Rome, Italy) from May through July 2010.

Men and women aged 18 years or older with moderate (Kellgren-Lawrence grade II or III), mono or bilateral knee OA and pain lasting for at least three weeks were eligible for inclusion. The diagnosis of knee OA was established according to the American Rheumatism Association radiographic criteria.[13] Exclusion criteria were: inability or unwillingness to sign informed consent, previous surgery on the affected knee, intra-articular injections with steroids or hyaluronic acid in prior six months, physiotherapy for knee problems in prior six months, congenital or acquired inflammatory or neurological (systemic or local) diseases involving the knee, chronic treatment with steroids or non-steroidal anti-inflammatory drugs, cognitive or psychiatric disorders, pregnancy or breastfeeding. Patients with contraindications to heat therapy (cancer in prior two years or active cancer treatment, local thrombosis, impaired arterial circulation, altered cutaneous thermal sensitivity, local or systemic acute infections, metal implants or prosthesis, severe osteoporosis) were also excluded.

The study protocol was approved by the Catholic University's Ethics Committee.

Randomization

Eligible participants were referred to a physician not involved in the study and provided with detailed information about the experimental protocol. Informed consent was obtained from each participant prior to treatment allocation. Patients were randomly assigned to either DHT or SHT using a random sequence generator (www.random.org). The randomization list was kept by an independent researcher not involved in the study. Allocation concealment was performed using closed envelopes, and the assignment code of each patient revealed to the physi-

otherapist who performed the treatment only at the beginning of the therapeutic protocol.

Information pertaining to demographics, education, lifestyle habits, pain duration, comorbidity and medications was collected using a dedicated questionnaire.

Outcomes

The primary outcome measure was the Italian version of the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index for the assessment of joint pain, stiffness, and physical function limitations.[14] Secondary outcome measures included the British Medical Research Council (BMRC) rating scale for the evaluation of muscle strength [15] and a visual analogue scale (VAS) for pain assessment.[16] Outcome measures were determined at baseline and follow-up visits by an investigator blind to the participant allocation.

Interventions

Both treatments were provided at the outpatient clinic of the Department of Gerontology, Geriatrics and Physiatrics. DHT was administered by using a dedicated device (Smarterapia Sigma Hyperthermia System, Easytech srl, Borgo San Lorenzo, Italy). The system was equipped with a 434-MHz microwave generator, with a maximum output power of 100 W, and a microstrip antenna applicator specific for semicylindrical joint volumes of 20 – 30 cm in diameter, with a total radiating area of 240 cm^2 and an effective field size (50% specific absorption rate; SAR) on a surface of 96 cm^2. A 0.5-cm thick silicone pad filled with thermostatic deionized water was applied on the knee to allow the greatest energy transfer to be achieved while preventing overheating of superficial tissues near the radiant source. The pad was placed approximately 2 cm above the patella, with the patient lying supine and the knee at 30° of flexion. The output power was set at 40 W and the silicone pad water temperature kept at 38 °C. The skin pilot temperature was set to a value aimed at achieving a 1.5 °C DT according to the thickness of the subcutaneous fat of each patient. The accuracy of the temperature control system in the treatment area was ±0.2 °C. Patients received a total of 12 treatment sessions (three sessions a week for four weeks) of 30 min each.

SHT was administered by using the pad of the hyperthermia device kept warm at 38°C without switching on the microwave generator. Both DHT and SHT were administered by a physiotherapist versed in the procedure and who was the only person involved in the study aware of the patient allocation.

For the time between the start of treatment and the 24-week follow-up, patients in the two groups were asked to refrain from any additional pharmacological or physical treatment for knee pain. Participants in the two groups were not prescribed any specific exercise program over the 12-month follow-up.

Endpoints

All patients were evaluated before treatment (baseline, T_0), at the end of the treatment (T_1), and at four (T_2), twelve (T_3), and twenty-four weeks (T_4) after the completion of the study protocol for all outcome measures. Twelve months after the last assessment, the WOMAC scale was re-administered (T_5).

Statistical analysis

Sample size was calculated according to the primary outcome measure (WOMAC scale). Assuming that the two treatments would be equally effective in determining a 15-point increase in the WOMAC summary score (minimal clinically important difference, MCID) [17] a sample size of 22 cases per treatment arm was determined using an a priori model of power analysis and a two-sided alternative hypothesis, given an α=0.05 and a power (1-β) =0.80. The number of participants was increased to 27 per group to account for a 20% rate of loss at follow-up.

Statistical analysis was performed using the SPSS v.19.0 software (SPSS Inc.; Chicago, IL). For all variables, normality of data was ascertained by the Kolmogorov-Smirnov's test. Differences between groups in WOMAC, BMRC and VAS scores over time were analyzed via analysis of covariance (ANCOVA) for repeated measures. Models were adjusted for age, sex and baseline values. A two-factor (time and group) analysis was performed to evaluate the overall group effect, overall time effect, and the interaction between group and time. Multiple pairwise comparisons within groups were performed by means of paired t-tests with Bonferroni's correction in order to determine the time-

point at which the observed effect occurred. For each variable, 95% confidence intervals (CIs) for mean differences were determined. For all tests, significance was set at P<0.05. Data pertaining to the 12-month follow-up were analyzed via an ANCOVA model only including WOMAC scores at T_1, T_4 and T_5. Missing data at follow-up were managed through the Last Observation Carried Forward (LOCF) method. Analyses were performed according to the intention-to-treat principle. All tests were two-sided, with results presented as mean ± standard deviation (SD).

Results

A total of 98 patients were eligible for inclusion, and 54 were randomized for the interventions (Figure 1). Baseline characteristics of the two treatment groups are shown in Table I. At T_0, participants in the two groups did not differ for any demographic or anthropometric parameter. Baseline scores at WOMAC, WOMAC subscales, BMRC and VAS were consistent between groups. All patients completed the treatment protocol. Three participants in the SHT group and two in the DHT group were lost at T_4. One patient in the SHT arm and two in the DHT group were lost at T_5. No adverse events were observed in either treatment arm.

Effects of treatments on primary and secondary outcome measures

Descriptive statistics of primary and secondary outcome measures in the two treatment groups over the 24-week follow-up is depicted in Table II. A significant group effect was detected for the primary outcome measure (WOMAC) (F=19.28; P<0.0001), resulting from a greater score reduction in the DHT group relative to participants receiving SHT. Significant time effect (F=11.61; P<0.0001) and time ´ group interaction (F=9.992; P<0.0001) were also determined. In the DHT group, a reduction in the WOMAC summary score relative to T_0 was observed at each follow-up time-point (Table III). The average WOMAC score decreased by approximately 18 points from baseline to T_1 and leveled off thereafter. Differences in the WOMAC score between T_0 and $T_{1\text{-}4}$ were greater than 15 points, which corresponds to the MCID for this tool. Conversely, in the SHT group, no significant changes in the WOMAC score were observed across time-points. The pattern of changes of WOMAC subscores (*i.e.*, pain, stiffness and function) over time in the two treatment arms was comparable to that observed for the summary score (Figure 2). At 12 months of follow-up (T_5), improvements in the WOMAC summary score as well as in pain, stiffness and function subscores were maintained in the DHT group (Figure 3). No changes were observed in patients treated with SHT.

Analysis of BMRC scores showed a significant group effect (F=5.954; P=0.0002) in favor of DHT as well as significant time effect (F=7.757; P=0.0062) and time ´ group interaction (F=2.546; P=0.0425). In the DHT group, the BMRC score increased from T_0 through T_2, with a plateau thereafter (Table IV). As a result, BMRC scores at follow-up were significantly higher than baseline. In contrast, in the SHT group, no changes in the BMRC score were detected over time, except for a marginal increase, approaching the statistical significance, from T_0 through T_2.

Finally, analysis of VAS scores revealed an overall group effect (F=30.34; P<0.0001) in favor of DHT, an overall time effect (F=13.64; P<0.0001) and a significant time ´ group interaction (F=6.445; P<0.0001). In the DHT group, a decrease in the VAS score relative to baseline was detected at each follow-up time-point (Table V). Specifically, the VAS score decreased by approximately 2.4 points from T_0 to T_1, and remained substantially stable thereafter. This change is greater than the MCID for the 10-cm VAS, corresponding to 1.3 points.[18] In the SHT group, a decrease in the VAS score, approaching the statistical significance, was observed from T_0 through T_2. However, scores at T_3 and T_4 were similar to those recorded at baseline. None of these changes was above the MCID for the tool.

Discussion

The main objective of the study was to compare the effects of deep versus superficial heating on pain and function in patients affected by moderate knee OA. DHT delivered through microwave diathermy produced a significant therapeutic effect in all outcomes considered. Improvements elicited by DHT were maintained over 12 months of follow-up. Conversely, patients receiving SHT did not experience clinical relevant changes in any outcome meas-

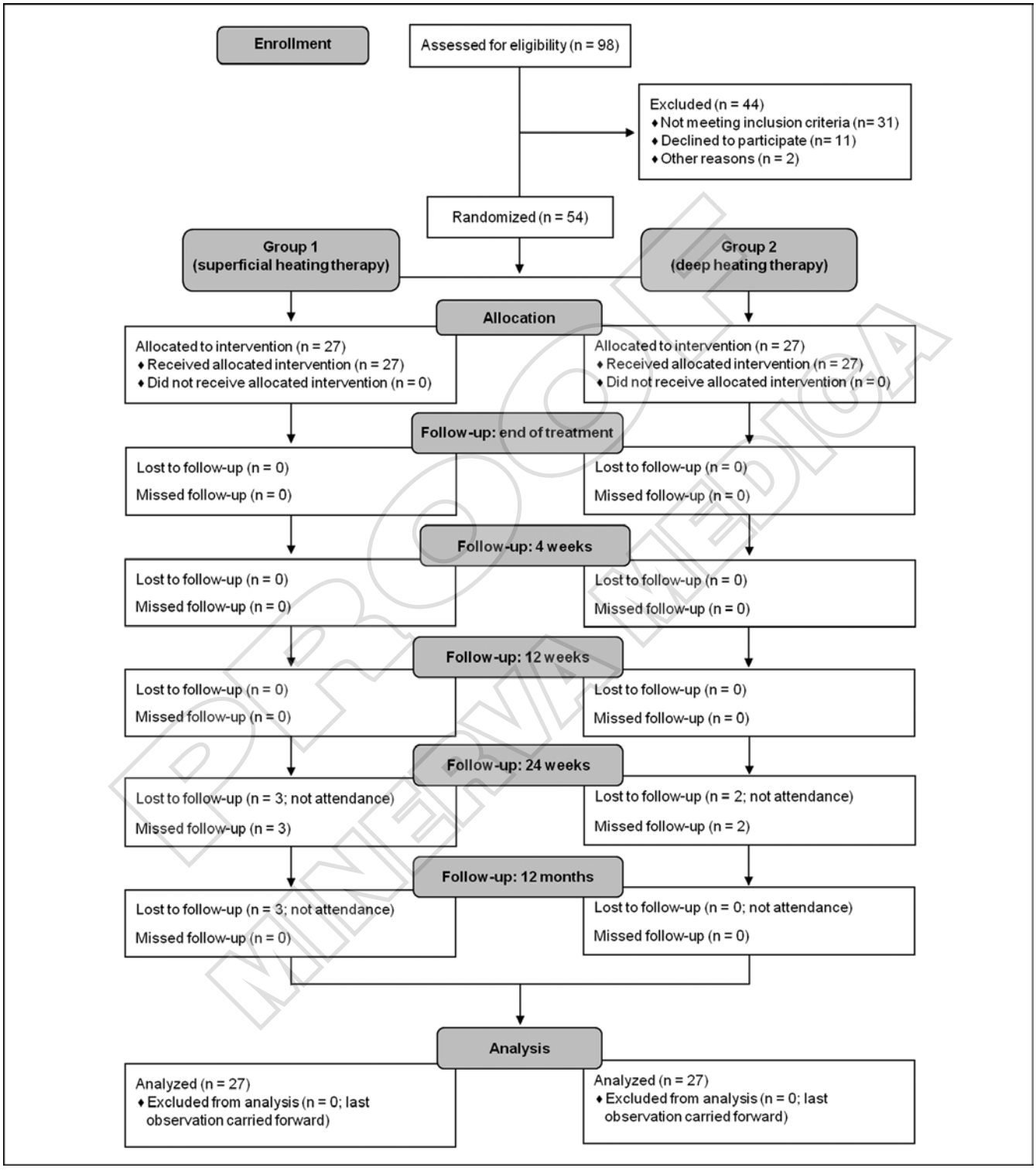

Figure 1.—Patients enrolled.

TABLE I.—*Baseline characteristics of the study population according to treatment allocation.*

Variable	Superficial heating therapy (n = 27)	Deep heating therapy (n = 27)	P value
Age (years)	66.3 ± 11.6	64.0 ± 9.8	0.44
Sex (M / F)	5 / 22	4 / 23	0.89
BMI	27.0 ± 3.9	27.4 ± 4.8	0.71
WOMAC summary score	46.0 ± 19.6	41.0 ± 16.7	0.36
WOMAC pain subscore	9.6 ± 4.2	7.8 ± 3.6	0.13
WOMAC stiffness subscore	3.7 ± 2.5	3.8 ± 1.7	0.86
WOMAC function subscore	32.7 ± 14.0	29.4 ± 12.4	0.42
VAS score	6.2 ± 2.0	5.3 ± 2.0	0.18
BMRC score	4.5 ± 0.7	4.4 ± 0.8	0.55

TABLE II.—*Primary and secondary outcome measures at T_1 through T_4 in the two treatment arms.*

	Superficial heating therapy (n = 27)	Deep heating therapy (n = 27)	P value
WOMAC score			
T_1	42.3 ± 20.8	22.3 ± 16.2	0.015
T_2	44.2 ± 16.6	21.2 ± 16.6	0.012
T_3	48.3 ± 18.2	24.5 ± 18.3	0.008
T_4	47.7 ± 16.2	24.4 ± 19.9	0.008
BMRC score			
T_1	4.7 ± 0.5	4.7 ± 0.5	0.760
T_2	4.7 ± 0.4	5.0 ± 0.0	0.084
T_3	4.7 ± 0.5	5.0 ± 0.0	0.058
T_4	4.7 ± 0.5	5.0 ± 0.0	0.084
VAS score			
T_1	5.2 ± 2.2	2.9 ± 2.1	0.016
T_2	5.4 ± 2.1	2.6 ± 1.8	0.008
T_3	6.0 ± 2.0	2.9 ± 2.1	0.005
T_4	6.3 ± 2.2	2.9 ± 2.5	0.004

TABLE III.—*Differences in WOMAC scores within groups over 24 weeks of follow-up as determined by multiple pairwise comparisons.*

	Differences between means		P value*	95% C.I.	
	Time-points	Value		Lower limit	Upper limit
Superficial heating therapy	$T_0 - T_1$	-3.74	0.217	-11.55	4.073
	$T_0 - T_2$	-1.78	0.525	-9.59	6.04
	$T_0 - T_3$	2.26	0.426	-5.56	10.07
	$T_0 - T_4$	1.67	0.550	-6.15	9.48
	$T_1 - T_2$	1.96	0.485	-5.85	9.78
	$T_1 - T_3$	6.00	0.079	-1.81	13.81
	$T_1 - T_4$	5.41	0.102	-2.41	13.22
	$T_2 - T_3$	4.04	0.189	-3.78	11.85
	$T_2 - T_4$	3.44	0.249	-4.37	11.26
	$T_3 - T_4$	-0.59	0.828	-8.41	7.22
Deep heating therapy	$T_0 - T_1$	-18.67	0.002	-26.48	-10.85
	$T_0 - T_2$	-17.96	0.002	-25.78	-10.15
	$T_0 - T_3$	-17.22	0.003	-25.04	-9.41
	$T_0 - T_4$	-17.70	0.002	-25.52	-9.89
	$T_1 - T_2$	0.70	0.800	-7.11	8.52
	$T_1 - T_3$	1.44	0.602	-6.37	9.26
	$T_1 - T_4$	0.96	0.725	-6.85	8.78
	$T_2 - T_3$	0.74	0.786	-7.07	8.56
	$T_2 - T_4$	0.26	0.924	-7.56	8.07
	$T_3 - T_4$	-0.48	0.900	-8.23	7.33

* Bonferroni correction for multiple comparisons

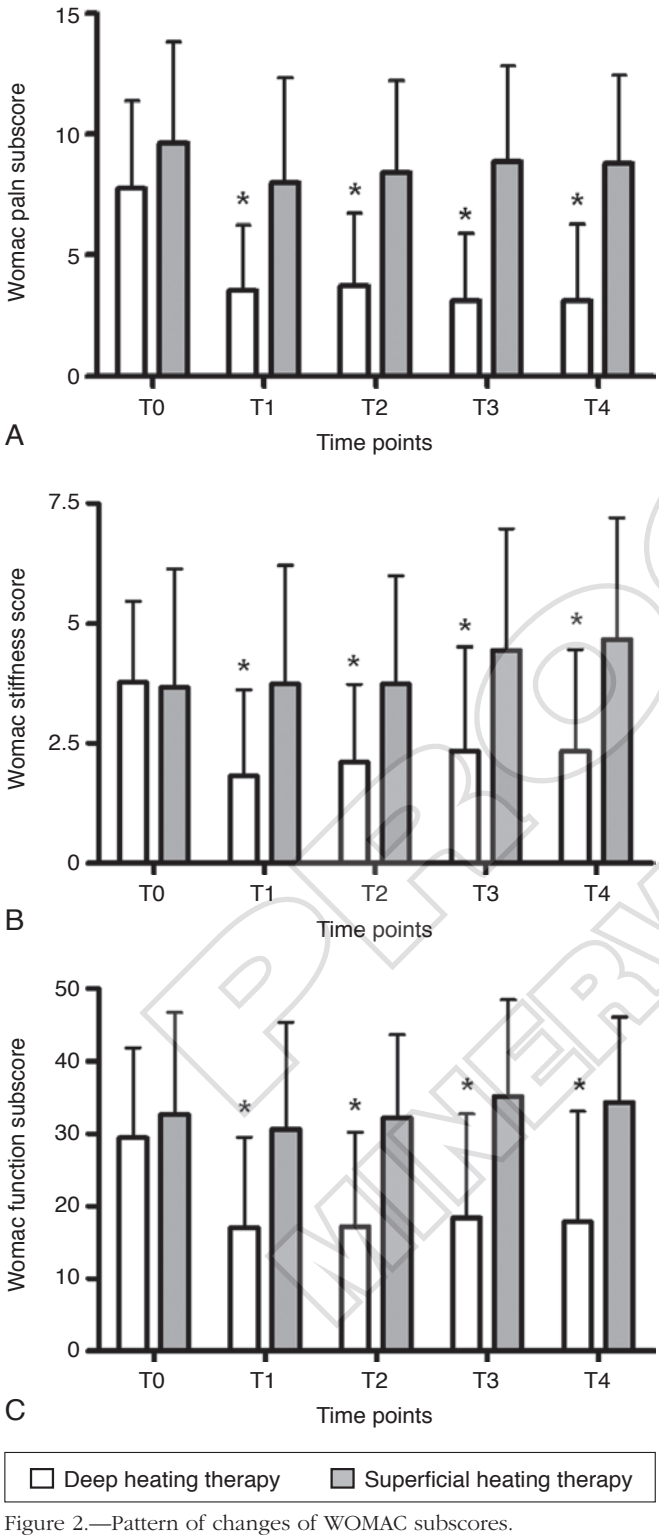

Figure 2.—Pattern of changes of WOMAC subscores.

ure. Marginal, transient improvements were only observed at the BMRC and VAS, likely as a result of a placebo effect. Collectively, our results indicate that DHT, but not SHT is effective in relieving pain and improving physical function in patients with moderate knee OA, with benefits maintained over the long term.

Results from the present study are in agreement with a recent paper by Giombini *et al.*,[11] who reported improvements in pain and physical performance in patients affected by moderate knee OA subjected to a similar microwave diathermy protocol. Ameliorations of pain severity, joint stiffness and physical performance were maintained over a 12-week follow-up. Our findings confirm and extend these observations by showing that benefits elicited by DHT are retained over a longer period of time (*i.e.*, 12 months).

Mechanisms of action of heat therapy are still under investigation. However, it is believed that the increase in local blood flow secondary to tissue heating may convey most benefits.[10] Delivery of nutrients and oxygen is enhanced following deep heating, thus facilitating tissue repair. Furthermore, the increased capillary permeability induced by DHT allows macrophages and granulocytes to reach the affected area, therefore promoting the removal of toxins and necrotic debris.[19] Noteworthy, the activity of cartilage degrading enzymes is blunted following joint heating by microwave diathermy.[20] In addition, hyperthermia can interfere with the activity of collagenase, oxygenase and other enzymes involved in the inflammatory process.[21] Finally, local microwave diathermy may induce the expression of heat shock proteins,[22] which in turn are essential for proper protein folding and removal of cellular waste material.

Improvements in pain and function observed in patients treated with DHT and their maintenance over time may be attributed to the stimulation of cellular repairing process and lessen of inflammation secondary to deep tissue heating. In this regard, DHT through shortwave diathermy has shown to reduce synovial thickness in patients with knee OA.[23] Noticeably, synovitis has been associated with the intensity of knee pain and the progression of cartilage loss in OA.[24] However, such an anti-inflammatory effect was not observed by others. In fact, Callaghan *et al.*,[25] found that joint inflammation, measured via radioleucoscintigraphy, was unaffected by shortwave diathermy in knee OA patients.

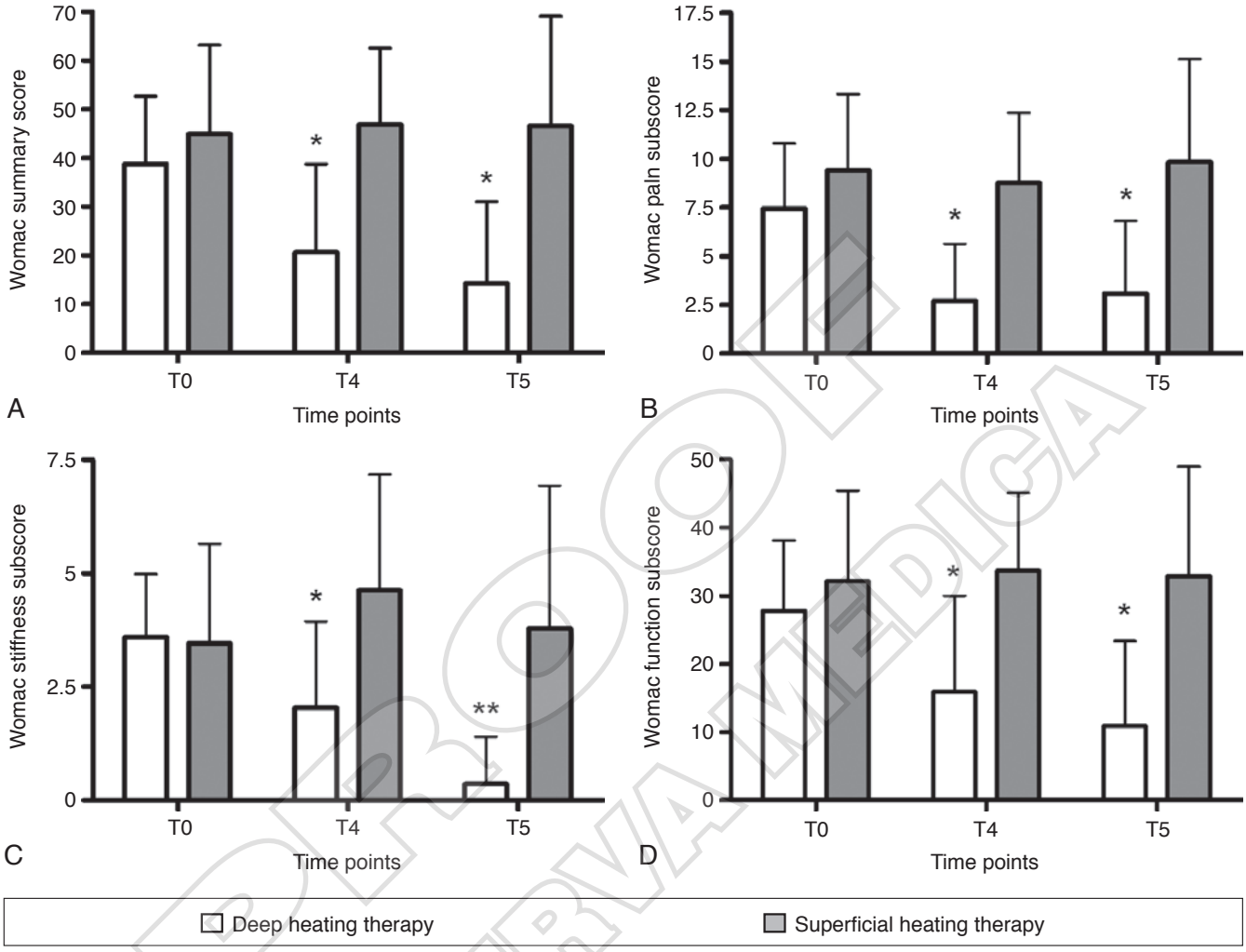

Figure 3.—WOMAC summary score and pain, stiffness and function subscores in the DHT group.

The amelioration of pain severity might also result from a reduction in sensory nerve conduction velocity, with subsequent decrease in the pool of afferent signals carrying pain stimuli.[26] Alternatively, DHT may inhibit nociceptive transmission by activating A-alpha and A-beta nerve fibres, according to the gait control theory.[27] Whether physiological changes elicited by DHT may hamper the progression of OA warrants further investigation.

With regard to the improvement in muscle strength in diathermy-treated patients, it is conceivable that it might have resulted from the reduced inhibition of muscular contraction secondary to pain relief. Indeed, studies have shown that DHT via shortwave diathermy promotes muscular relaxation and improves tissue flexibility.[28,29] In addition, the increased oxygen and nutrient supply, due to the enhanced local blood flow, may ameliorate muscular mitochondrial oxidative phosphorylation, thus increasing ATP availability.[30]

The lack of clinical relevant changes in the SHT group was likely the result of the inability, intrinsic to this treatment modality, of inducing deep tissue heating. This, in turn, could have prevented the increase in local blood flow and the occurrence of downstream physiological and biochemical adap-

TABLE IV.—*Differences in BMRC scores within groups over 24 weeks of follow-up as determined by multiple pairwise comparisons.*

	Differences between means		P value*	95% C.I.	
	Time-points	Value		Lower limit	Upper limit
Superficial heating therapy	$T_0 - T_1$	0.22	0.089	-0.08	0.53
	$T_0 - T_2$	0.26	0.059	-0.04	0.56
	$T_0 - T_3$	0.22	0.089	-0.08	0.53
	$T_0 - T_4$	0.22	0.089	-0.08	0.53
	$T_1 - T_2$	0.04	0.728	-0.27	0.34
	$T_1 - T_3$	0.00	1.000	-0.30	0.30
	$T_1 - T_4$	0.00	1.000	-0.30	0.30
	$T_2 - T_3$	-0.04	0.728	-0.34	0.27
	$T_2 - T_4$	-0.04	0.728	-0.34	0.27
	$T_3 - T_4$	0.00	1.000	-0.30	0.30
Deep heating therapy	$T_0 - T_1$	0.26	0.059	-0.04	0.56
	$T_0 - T_2$	0.59	0.004	0.29	0.90
	$T_0 - T_3$	0.59	0.004	0.29	0.90
	$T_0 - T_4$	0.56	0.005	0.25	0.86
	$T_1 - T_2$	0.33	0.028	0.03	0.64
	$T_1 - T_3$	0.33	0.028	0.03	0.64
	$T_1 - T_4$	0.30	0.041	0.00	0.60
	$T_2 - T_3$	0.00	1.000	-0.30	0.30
	$T_2 - T_4$	-0.04	0.728	-0.34	0.27
	$T_3 - T_4$	-0.04	0.728	-0.34	0.27

*Bonferroni correction for multiple comparisons

TABLE V.—*Differences in VAS scores within groups over 24 weeks of follow-up as determined by multiple pairwise comparisons.*

	Differences between means		P value*	95% CI	
	Time-points	Value		Lower limit	Upper limit
Superficial heating therapy	$T_0 - T_1$	-1.00	0.060	-2.18	0.18
	$T_0 - T_2$	-0.85	0.091	-2.030	0.33
	$T_0 - T_3$	-0.19	0.656	-1.36	0.99
	$T_0 - T_4$	0.04	0.928	-1.14	1.22
	$T_1 - T_2$	0.15	0.720	-1.03	1.33
	$T_1 - T_3$	0.81	0.102	-0.36	1.99
	$T_1 - T_4$	1.04	0.055	-0.14	2.22
	$T_2 - T_3$	0.67	0.159	-0.51	1.85
	$T_2 - T_4$	0.89	0.082	-0.29	2.07
	$T_3 - T_4$	0.22	0.595	-0.96	1.40
Deep heating therapy	$T_0 - T_1$	-2.37	0.004	-3.55	-1.19
	$T_0 - T_2$	-2.70	0.002	-3.88	-1.53
	$T_0 - T_3$	-2.44	0.003	-3.62	-1.27
	$T_0 - T_4$	-2.41	0.003	-3.59	-1.23
	$T_1 - T_2$	-0.33	0.436	-1.5	0.85
	$T_1 - T_3$	-0.07	0.857	-1.25	1.10
	$T_1 - T_4$	-0.04	0.928	-1.22	1.14
	$T_2 - T_3$	0.26	0.538	-0.92	1.44
	$T_2 - T_4$	0.30	0.485	-0.88	1.48
	$T_3 - T_4$	0.04	0.928	-1.14	1.22

*Bonferroni correction for multiple comparisons

tations, which are believed to mediate the benefits of hyperthermia. Moreover, hot packs increase the superficial temperature only during their application, whereas deep tissue heating by microwave diathermy persists for a longer period of time after the end of the treatment session. In contrast to

our findings, Güngen *et al*.[31] have recently shown that the application of hot packs at 42-45 °C improves pain both at rest and during activities as well as physical performance in patients with knee OA. Benefits were maintained over three months of follow-up. Discrepancies between our findings and those by Güngen *et al*.[31] could be attributed to differences in the temperature employed (42-45 °C *vs.* 38 °C). In addition, it should be noted that the WOMAC summary score improved of approximately five points following SHT at 42-45 °C. This change is below the MCID threshold for the tool. Furthermore, in agreement with our study, Evcik *et al*.[32] reported a modest, transient reduction in pain severity in patients with knee OA subjected to the application of hot packs at 42 °C. This benefit was lost at three months of follow-up. In addition, Robertson *et al*.[29] showed that application of hot packs, contrary to DHT, did not affect muscular flexibility and relaxation. Collectively, these observations question the efficacy of hot pack therapy as a standalone treatment modality in knee OA. However, SHT may still be beneficial in combination with other rehabilitative treatments. Indeed, Cetin *et al*.[27] found that hot packs combined with isokinetic exercise improved physical performance and alleviated joint pain in patients with knee OA compared with those receiving isokinetic exercise only. However, improvements were greater when physical exercise was combined with shortwave diathermy, further supporting the superiority of DHT relative to SHT.

In summary, our findings add to a growing literature indicating that localized microwave diathermy is an effective means to improve pain and function in a variety of musculoskeletal conditions, ranging from OA [11] to carpal tunnel syndrome [33] and shoulder tendinopathies.[34-36] In contrast, our data do not support SHT at the temperature used in the present study as a standalone symptomatic treatment for knee OA.

Strengths and limitations

Our study has several strengths, including the randomized double-blind design, treatments provided by experienced personnel, excellent compliance to protocols with very low rates of loss at follow-up, extended follow-up, multidimensional evaluation of the patient function and symptoms, and intention-to-treat analysis. However, only participants with moderate knee OA (*i.e.*, Kellgren-Lawrence grade II or III) were enrolled in the study. Therefore, results may not be extended to patients with more severe OA. Furthermore, radiographic examinations were not performed at follow-up, which does not allow to infer about the effects of treatments on disease progression. In addition, it is possible that SHT at a higher temperature might have produced better pain control and greater functional improvements. However, by applying a water bolus at 38 °C, patients in the two groups perceived the same warmth sensation, rendering the two treatments indistinguishable to participants. Finally, the microwave diathermy equipment is quite expensive and is only available in specialized centers, which may preclude the large-scale implementation of this treatment modality. However, a growing number of studies indicates that localized microwave diathermy is effective in the conservative management of several musculoskeletal conditions, thus reducing the associated disability burden. Hence, the equipment cost may be offset by decreased OA-related healthcare and indirect expenditures (*e.g.*, sick leave).

Conclusions

DHT via microwave diathermy delivered three times a week for four weeks improves pain and function in patients affected by moderate knee OA, with benefits retained for at least 12 months. No clinically relevant changes are observed in patients treated with SHT.

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