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Review

Effectiveness of thermal and athermal short-wave diathermy for the management of knee osteoarthritis: a systematic review and meta-analysis

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SUMMARY

Objective: To assess the effectiveness of short-wave diathermy (SWD) treatment in the management of knee osteoarthritis (KOA) and to assess whether the effects are related to the induction of a thermal effect.

Methods: A systematic literature search was conducted in PubMed, CINAHL, PEDro, EMBASE, SPORTdiscus and Scholar Google. Included were trials that compared the use of SWD treatment in patients diagnosed with KOA with a control group (placebo SWD treatment or no intervention) and studies that used high-frequency electromagnetic energy (i.e., 27.12 MHz) with sufficient information regarding treatment dosage. Methodological quality of the included studies was assessed in accordance with the PEDro classification scale. A minimum of a 6/10 score was required for inclusion.

Results: Seven studies were included in the final analysis. Treatment protocols (dosage, duration, number of treatments) varied extensively between studies. The meta-analysis of the studies with low mean power did not favour SWD treatment for pain reduction, while the results of studies employing some thermal effect were significant. No treatment effect on functional performance measures was determined.

Conclusion: This meta-analysis found small, significant effects on pain and muscle performance only when SWD evoked a local thermal sensation. However, the variability in the treatment protocols makes it difficult to draw definitive conclusions about the factors determining the effectiveness of SWD treatment. More research (using comparable protocols and outcome measurements) is needed to evaluate possible long-term effects of thermal SWD treatment and its cost effectiveness in patients with KOA.

Introduction

Knee osteoarthritis (KOA) is one of the most common forms of arthritis in the Western world, with a prevalence of 10–15% in adults over 60 years of age[1,2]. The primary impairments associated with KOA include pain, stiffness, joint instability, joint swelling, and muscle weakness. These impairments result in marked functional limitations that account for the highest percentage of disability in walking, stair-climbing, and housekeeping among the non-institutionalized elderly population, leading to a significant decrease in quality of life[3,4].

KOA is not a curable disease, and end-stage KOA is frequently treated by surgical procedures[5,6]. During the course of the disease, patients receive a variety of pharmacological and non-pharmacological treatments aimed at alleviating the signs and symptoms of the disease and, if possible, slowing its progression[7]. A number of medical guidelines have been developed to assist caregivers in the choice of therapy for the management of KOA, and the majority of these guidelines include exercise and a variety of physical therapy modalities[6]. In fact, 78% of patients with KOA visiting a medical specialist also see a physical therapist[8].

Short-wave diathermy (SWD) is one of the oldest forms of electrotherapeutic modalities traditionally used by physical therapists to treat symptoms of KOA[9–11]. SWD typically utilizes electromagnetic radiation at 27.12 MHz, which is applied in either a continuous (CSWD) or a pulsed (PSWD) mode, with the latter delivered in the form of pulse trains[9,11]. In a survey of 41 Irish hospital-based physiotherapy departments, CSWD and PSWD were specified as treatments for acute osteoarthritis (OA) by 34.8% and

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73.9% of the respondents, respectively, and for chronic OA by 97.8% and 59.4% of the respondents, respectively[11]. It is generally accepted that the major physiological effects of CSWD are related to an induced increase in tissue temperature, which may induce vasodilatation, elevation of pain threshold, reduction in muscle spasm, acceleration of cellular activity, and increased soft tissue extensibility[11–13].

PSWD is generally used for its athermal effects[11–14] which are probably the result of the ability of cells to absorb energy from oscillating electrical fields of defined frequencies and/or amplitudes, thereby provoking or enhancing cellular activity[14,15]. The physiological effects attributed to PSWD include increased blood flow, decreased joint pain and stiffness, reduced inflammation, faster resolution of oedema and accelerated would healing[16]. The use of PSWD for arthritic joint treatment has increased dramatically in the last decade, probably due to the possible link between increased temperature resulting from CSWD and synovial inflammatory activity, and between synovial inflammatory activity and worsening of cartilage degeneration in OA[13,17]. Thus, in a recent survey in England the availability and use of CSWD has decreased while the opposite is true for PSWD[18].

However, while the introduction of PSWD was driven by it's possible athermal effects, studies have demonstrated that PSWD may also induce an elevation of tissue temperature that is dependent on the total average power delivered[19,20]. For example, Bricknell and Watson (1995)[21] demonstrated a definite thermal sensation, with an average power [standard deviation (SD)] of 10.9 (3.2)W, and Murray and Kitchen (2000)[20] determined a 'possible' thermal sensation and a 'definite' thermal sensation at a mean (SD) power of 13.8 (7.1)W and 21.2 (8.3)W, respectively. While a sensation of warmth at the skin level does not ensure deep tissue temperature increases, a study with PSWD at an average power of 48 W was shown to increase muscle tissue at 3 cm below the skin surface by a mean (SD) of 3.78 (1.19)°C, which was quite similar to the increase at skin level[19].

In a recent study, Al-Mandeel and Watson (2010)[22] examined, in a well controlled study, the effect of PSWD at a high and low mean power (24 W and 3 W respectively) and demonstrated significant physiological effects on blood volume and skin temperature primarily at the high dose treatment. Therefore, the physiological response to PSWD may also be related to its thermal effects, which are dose-dependent.

Despite the popularity of this modality, the effectiveness of CSWD/PSWD for the treatment of KOA has been only sporadically examined, and many of the earlier studies related to this issue are characterized by poor experimental design[23–26]. Several review papers have been published to assist the clinician in decision making regarding the choice of SWD as a treatment modality[9,11,13,27]. While these reviews generally recommend the need for additional well-controlled studies, they do not provide sufficient details to determine optimal dosage. Furthermore, as these reviews were not systematic meta-analysis they do not provided sufficient evidence as to the efficacy of this treatment modality.

One important limitation of these early reviews is that they do not include randomized controlled studies, conducted more recently. Furthermore, while two systematic reviews of randomized controlled trials have been recently published, these reviews do not differentiate between studies employing high-frequency energy (i.e., 27 MHz, frequency) classically referred to as SWD which can be delivered in a continuous or pulsed form, and those employing low radio frequency energy (i.e., radio frequency of 1–300 KHz)[28,29]. These two types of radio frequency energies involve different technologies and are reported to have different physiological effects, and therefore should not be combined as identical (see review by Guo *et al.*, 2011)[30].

The primary objective of this study was to systematically review the effectiveness of SWD treatment in the management of KOA. The secondary objective was to assess whether the effects of SWD treatment are related to the induction of a thermal effect. The present review was written in accordance with the guidelines recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[31].

Methods

Search strategy

An online search of PubMed (1966 to September 2011), CINAHL (1982 to September 2011), PEDro (last updated September 5, 2011), EMBASE (1974 to September 2011), SPORTdiscus (1830 to September 2011), and Scholar Google databases was performed independently by both authors. The electronic search was completed by a hand search of bibliographic references of the included studies.

The following medical subject headings by MeSH terms were used: OA, arthritis, diathermy, short-wave therapy. Keywords were KOA, knee arthritis, gonarthrosis, short-wave (or shortwave) diathermy, and short-wave treatment. No publication date or language was restricted, but the search was restricted to human studies. The search was initially conducted by the two authors independently and finalized by the authors in collaboration. The last full search was run on September 2011. Duplicated publications were removed after all databases and reference lists were searched. The titles and abstracts of all identified articles were reviewed, with the full article reviewed whenever deemed necessary to finalize a decision about inclusion.

Study selection and eligibility criteria

The authors independently screened all selected citations. The trials included were those that compared the use of SWD treatment in patients diagnosed with KOA with a control group receiving either placebo SWD treatment or no SWD intervention. Trials in which SWD treatment was supplemented by an additional modality (e.g., exercise) were included in the review only when the study also had a group receiving the additional intervention alone (e.g., exercise). Only studies that used high-frequency electromagnetic energy (i.e., 27.12 MHz), whether delivered in a continuous or pulsed mode, were selected for the final review. In addition, selected studies had to include sufficient information regarding treatment dosage in order to determine whether the intervention was thermal or athermal. Thus, articles that did not provide sufficient information to calculate mean Watt were included only if the authors specifically stated that the treatment was thermal or athermal. While, selection of study was not limited by study design (other than inclusion of control group) or outcome measures used, a minimum score of 6/10 on the PEDro classification scale was requited[32].

Data extraction

A data extraction sheet was developed by both reviewers, who then extracted the data independently. Differences between reviewers in regard to summary of the data were resolved by consensus. The reviewers contacted one author by e-mail for information not presented in the published paper[33].

Quality assessment

Methodological quality of the included studies was assessed in accordance with the PEDro classification scale[32], providing a score between 0 and 10. The PEDro ratings, which are provided by the

Centre for Evidence-Based Physiotherapy at the George Institute for Global Health, were used whenever available. Studies for which a PEDro score was not published were scored independently by the authors, with discrepancies settled by consensus. Studies were rated between excellent and poor on the basis of the PEDro score, as follows: 9–10 – excellent; 6–8 – good; 4–5 – fair; <4 – poor.

Data analysis

MetaAnalyst software was used to perform a meta-analysis where appropriate, that is, when sufficiently homogenous data concerning performance were available. When sufficient data were not reported to enable calculation of the effect size, the relevant author was contacted and the necessary data were requested. Effect size (Hedges G) was determined conservatively, based on comparisons of the final outcomes of the treatment and control groups, utilizing standardized scores and continuous random (DerSimonian-Laird) analysis, while assuming unequal variances.

Results

Study selection

Our literature search from all databases produced 71 studies. Title and abstracts were viewed to exclude duplicate publications (five studies), letters (one paper), review papers (three papers), use of radio frequency other than SWD (18 studies), and pathologies other than KOA (14 studies). Forty-one studies out of the 71 were excluded at this stage, and the remaining 30 were retrieved for full text review. Nineteen studies were excluded at this stage either because of lack of appropriate control group or insufficient data concerning treatment dose. Eleven articles complied with the review selection criteria, of which two more were excluded[34,35] since they were conducted by the same group. Following consultation with one of the primary authors of these studies, only the final publication of this series was included in our analysis[36]. Two additional studies were excluded at this stage due to a PEDro score of 4/10. Characteristics of the final seven studies retrieved are summarized in Tables I and II.

Methodological quality

The methodology quality of the included papers according to the PEDro classification scale is presented in Table III. Only one[36] of the studies was scored independently by the authors, while the remaining scores were provided by the PEDro database. The mean (SD) PEDro score was 7.28 (1.38), with two studies graded as excellent (score of 9/10)[36,37], and the rest in the good range (score of 6–8/10)[33,38–41]. One item (blind therapist) was scored positively in only one study[41], and one item (intention to treat) was scored positively in only two studies[36,37]. In contrast, three items (baseline comparable, between-groups comparison, and eligibility criteria) were scored positively in all included studies. Two of the studies involved a control group[33,38], three a placebo group[37,39,40] and two both a placebo and control groups[36,39,41].

Characteristics of included studies

Subjects

The included studies involved 594 patients (527 females), with 274 of them receiving SWD treatment and 320 serving as controls. The number of subjects per group ranged between 9 and 60, with a mean of 27 (SD – 12.7). Mean age was 62.5 years (SD – 5.07). KOA was confirmed in all subjects on the basis of radiological changes, with the exception of one study[37] in which eligibility was based on the diagnostic criteria of the American College of Rheumatology.

Intervention

Treatment dosage: Information regarding treatment dosage varied between studies. One study did not specify whether they used a continuous or pulsed mode nor were any other dosage parameters identified that could help us determine mean power or energy[38]. However, this study indicated specifically that intensity was set based on each individual's sensation of warmth determined as "a mild but pleasant sensation of heat." Of the remaining studies, only one used a continuous mode, with a relatively high mean power in the range of 120–132 W and a total energy of 108–118 KJ, inducing a strong thermal effect[33] (as determined through personal communication with the author).

Duration and number of treatments: The shortest treatment duration was 15 min[33,41], and the longest duration was 38 min[36], with 20 min being the most common treatment duration[36–40]. The total number of treatments varied from six treatments delivered over a period of 2 weeks[39] to a total of 24 delivered over a period of 8 weeks[33]. The mean (SD) number of treatments was 11.14 (5.92), carried out over a mean (SD) period of 3.71 (1.97) weeks.

Treatment groups and additional intervention

The number of treatment groups varied between two and five. The control groups received either placebo SWD or no SWD treatment. While the majority of the studies included only one group receiving SWD treatment, three studies involved two SWD treatment groups differing in dosage[36,39,40].

In three of the studies, the patients receiving SWD treatment were not offered any additional intervention during the treatment period[36,39,40]. Additional interventions in the remaining studies included exercise and hot packs.

Treatment effects

A summary of treatment effects reported in the various studies is presented in Table I (last column). Effect sizes and 95% confidence interval (CI) of the primary outcome measures, as well as the pooled effects computed when data were available for more than one study, are presented in Table IV. The *P*-values reported in the original studies are included in this table whenever insufficient data were available to calculate the effect size.

Body structure and function domain

All of the included studies assessed pain either using a visual analogue scale (VAS) or a Numeric Pain Rating Scale (NPRS). In two of these studies, pain was determined by the mean response to five questions, as rated on a VAS, which comprised the pain subscale in the Western Ontario and McMaster Universities osteoarthritis (WOMAC) questionnaire[38,40]. Results from all but one study[37] were pooled for the meta-analysis. However, since three studies involved two treatment groups differing in SWD dosage, the results of only one treatment group per study was included in the overall pooled analysis so as to account for possible within-study bias. The group chosen was the one that demonstrated the strongest positive effect[36,39,40].

Overall analysis did not quite reach significance in terms of pain reduction [Effect size (CI) −0.414 (−0.857, 0.030)] (Table IV, Fig. 1). The study that could not be pooled in the meta-analysis, reported no such effect[37]. In an attempt to identify whether treatment dose explained the inconsistency between groups, separate analyses were conducted for the studies with mean power $\leq$10 W[39,40] and for those with mean power greater than 10 W. The effect estimates of the studies with low mean power did not favour SWD treatment, while the pooled results of studies employing some thermal effect were statistically significant [Effect size (CI) −0.334 (−0.643, −0.026)].

The results of two out of the three studies that examined muscle strength with a focus on isokinetic knee motion could be pooled for

Table I
Study characteristics

Study	Age Mean (SD)	BMI Mean (SD)	Gender M/F	Groups	No. per Group	Test time	Outcome measures	Results
Akyol, 2010[38]	57.8 (10.7) 56.6 (8.1)	31.1 (5.2) 30.8 (3.6)	Females only	Gr1: SWD +ex' Gr 2: Control (ex' only)	20 20	Pre; Post‡; & 3 mo. FU	Body structure & function Pain VAS; isokinetic torque of knee flexors & extensors; Beck depression inventory Activity 6 min walk test; WOMAC; SF-36	Significant time effect on all measures; no group effect
Callaghan, 2005[39]	59.5 (6.7) 58.3 (7.3) 63.5 (7.9)	29.9 (4.3) 26.8 (3.9) 27.2 (4.5)	14/13	Gr 1: Low SWD Gr 2: High SWD Gr 3: Placebo	9 9 9	Pre & Post‡	Body structure & function ROM; pain VAS; peak concentric torque of knee extensors; joint inflammation measured with radio-leucoscintigraphy Activities 13 m gait velocity	No time effect; No group effect except for ROM which improved significantly more in the placebo group
Cetin, 2008[33]	59.8 (11.6) 61.9 (8.6) 57.6 (7.3) 61.1 (8.3) 58.9 (9.1)	27.9 (4.2) 29.5 (4.6) 29.8 (5.7) 27.7 (4.2) 27.4 (4.2)	Females only	Gr 1: SWD + HP + ex' Gr 2: TENS + HP + ex' Gr 3: US + HP + ex' Gr 4: Control (HP + ex')† Gr 5: Control (ex')	20 20 20 20 20	Pre; Post‡	Body structure & function Pain VAS; isokinetic strength knee extension Lequesne Index of knee Activity 50 m walk velocity	Greater significant decreases in pain, muscle strength in SWD Gr. vs control Gr; significant time effect on walking velocity with no group effect
Fukuda, 2011[36]	62.0 (8.0) 63.0 (9.0) 57.0 (9.0) 61.0 (10.0)	29.4 (4.5) 27.1 (4.2) 27.6 (3.7) 26.7 (3.0)	Females only	Gr 1: Low SWD Gr 2: High SWD Gr 3: Placebo Gr 4: Control*	32 31 23 35	Pre; Post‡; & 12 mo. FU	Body structure & function Pain VAS Activities KOOS questionnaire	Significant reduction in pain and improvement in function of both low and high SWD vs control or placebo groups. No differences between treatment groups
Klaber Moffett, 1996[41]	62.7 (8.7) 63.5 (10.5) 64.4 (10.3)	–	34/58	Gr 1: SWD Gr 2: Placebo Gr 3: Control *	30 30 30 46 knee, 46 hip	Pre; post‡; 4 & 12-week FU	Body structure & function Daily pain diary (0-100 scale); General Health questionnaire; (ADL & ROM assessed but no reported)	Significant time effect; no group effect for any of the measures
Laufer, 2005[40]	72.7 (6.4) 74.8 (6.6) 73.3 (6.9)	–	21/82	Gr 1: Low SWD Gr 2: High SWD Gr 3: Placebo	32 38 33	Pre; post‡; 12-week FU	Activities Timed Get-Up & Go Test; stair negotiation; 3-min walk; WOMAC	Significant time effect for pain and stiffness, with no group effect
Rattanachaiyanont, 2008[37]	63.3 (7.6) 62.5 (8.5)	25.6 (4.0) 26.2 (4.2)	Females only	Gr1: SWD + ex Gr 2: Placebo + ex	53 60	Pre; Post‡; & 3-week FU	Activity 100 m walking velocity; stair negotiation time; Modified WOMAC; global assessment; patient satisfaction	Significant time effect; no group effect

M/F – male/female; ex' – exercises; FU – follow up; ADL – activities of daily living; WOMAC – Western Ontario MacMaster Questionnaire; SF-36 – short form (36) health survey.
* Control = no intervention.
† The control group used for meta-analysis.
‡ Post – following the completion of last treatment.

Table II
Treatment characteristics

Study	Unit/company	Energy transfer method	Electrode/ applicator	Continuous/ pulsed	Thermal/ athermal	Peak (W)	Pulse duration (μsec)	Freq. (Hz)	Mean Watt	Rx duration (min)	Energy (KJ)	No. of Rxs	Other interventions
Akyol, 2010[38]	Curapuls 419/ Enraf-Nonius	Inductive	Coil	–	Mild thermal	–	–	–	–	20	–	4 wks; total: 12	Both groups: isokinetic exercise
Callaghan, 2005[39]	Megapulse/EMS	Inductive	Drum†	Gr. 1: Pulsed Gr. 2: Pulsed	Athermal Possible thermal		200 400	400 400	10 20	20 20	12* 24*	2 wks; total: 6	None
Cetin, 2008[33]	Curapuls 419/Enraf-Nonius	Capacitive	–	Continuous†	Thermal†	–	–	–	120–132†	15	108–118*,†	8 wks; total 24	Groups 1–4: HP & exercise Group 5: exercise
Fukuda, 2011[36]	Diatermed II/Carci	Capacitive	Soft electrodes	Gr. 1: Pulsed Gr. 2: Pulsed	Possible thermal Possible thermal	250 250	400 400	145 145	14.5 14.5	19 38	17 33	3 wks; total: 9	None
Klaber Moffett, 1996[41]	Ultramed/Bosch	Inductive	Drum (circuplode)	Pulsed	Possible thermal	–	–	82	23	15	20*	3 wks; total: 9	Exercise & diet instructions to all groups
Laufer, 2005[40]	Curapuls 670/Enraf-Nonius	Inductive	Drum (circuplode)	Gr. 1: Pulsed Gr. 2: Pulsed	Athermal Mild thermal	200 200	82 300	110 300	1.8 18	20 20	2.1* 21*	3 wks; total: 9	None
Rattanachaiyanont, 2008[37]	Ultramed/Bosch	Capacitive	Condenser plate	Pulsed	Athermal	300	–	–	3.2	20	3.8*	3 wks; total: 9	Both groups: exercise, NSAID as needed

* Calculated by the authors using the following formula: *total energy* (J) = *mean power* (W) × *application time* (s).
† Personal communication.

Table III
Summary of methodological quality based on the PEDro classification scale

Study	Overall	Eligibility criteria†	Random allocation	Concealed allocation	Baseline comparable	Blind subject	Blind therapist	Blind assessor	Adequate follow-up	Intention to-treat	Between-group comparison	Point estimates & variability
Akyol, 2010[38]	7	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes
Callaghan, 2005[39]	6	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes
Cetin, 2008[33]	6	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes
Fukuda, 2011* [36]	9	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Klaber Moffett, 1996[41]	8	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Laufer, 2005[40]	6	Yes	No	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Rattanachaiyanont, 2008[37]	9	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Summary (Yes/no)		**7/7**	**6/7**	**4/7**	**7/7**	**4/7**	**1/7**	**7/7**	**6/7**	**2/7**	**7/7**	**7/7**

* Rated by authors.
† Eligibility criteria item does not contribute to total score.

Table IV
Summary of treatment effects (reported *P* value, effect size and 95% CI)

Study name	Measure	Reported *P* value*	Effect size	95% CI (lower & upper)	
Body structure and function domain					
Pain					
[a]Akyol, 2010[38]	VAS		−0.493	−1.123	0.137
[b]Akyol, 2010[38]	WOMAC (pain)		−0.113	−0.734	0.507
[c]Callaghan, 2005[39] (LD)	VAS		−0.473	−1.365	0.419
[d]Callaghan, 2005[39] (HD)	VAS		−0.328	−1.212	0.556
[e]Cetin, 2008[33]	VAS		−0.098	−0.718	0.523
[f]Fukuda, 2011[36] (LD)	NPRS		−1.439	−2.068	−0.810
[g]Fukuda, 2011[36] (HD)	NPRS		−0.982	−1.579	−0.386
[h]Klaber-Moffett, 1996[41]	NPRS		−0.026	−0.594	0.542
[i]Laufer, 2005[40] (LD)	WOMAC (pain)		0.082	−0.384	0.549
[j]Laufer, 2005[40] (HD)	WOMAC (pain)		−0.119	−0.606	0.368
[k]Rattanachaiyano, 2008[37]	WOMAC (pain)	NS	–	–	–
Pooled effect: Overall: a, d, e, f, h & j			**−0.408**	**−0.837**	**0.022**
Pooled effect Thermal: a, d, e, g, h, & j			**−0.327**	**−0.627**	**−0.028**
Pooled effect Athermal: c & i			**−0.060**	**−0.535**	**0.415**
Muscle strength					
[a]Akyol, 2010[38]	Isokinetic left knee extension at 60°/s		0.404	−0.223	1.030
[b]Cetin, 2008[33]	Isokinetic left knee extension at 60°/s		0.528	−0.104	1.159
[c]Callaghan, 2005[39] (LD)	Concentric knee extension 90°/s		0.348	−0.277	0.973
[d]Callaghan, 2005[39] (HD)	Concentric knee extension 90°/s		0.492	−0.138	1.122
Pooled effect: a & b			**0.465**	**0.020**	**0.910**
Joint inflammation					
Callaghan, 2005[39] (LD)	Radio-leucoscintigraphy		−0.289	−0.912	0.334
Callaghan, 2005[39] (HD)	Radio-leucoscintigraphy		0.218	−0.404	0.840
ROM					
Callaghan, 2005[39] (LD)	Knee joint		−0.398	−1.025	0.228
Callaghan, 2005[39] (HD)	Knee joint		0.376	−0.250	1.002
Activity domain					
Activity questionnaires					
[a]Akyol, 2010[38]	WOMAC (function)		−0.247	−0.869	0.376
[b]Cetin, 2008[33]	Lequesne Index		−0.022	−0.642	0.598
[c]Fukuda, 2011[36] (LD)	KOOS		1.141	0.562	1.721
[d]Fukuda, 2011[36] (HD)	KOOS		0.999	0.425	1.572
[e]Laufer, 2005[40] (LD)	WOMAC (function)		0.048	−0.418	0.515
[f]Laufer, 2005[40] (HD)	WOMAC (function)		−0.081	−0.567	0.406
[g]Rattanachaiyano, 2008[37]	WOMAC (total)	NS			
Pooled effect of a & f			−0.144	−0.527	0.240
Gait performance					
Akyol, 2010[38]	6 MWT (m)		0.088	−0.532	0.708
Callaghan, 2005[39] (LD)	13 m walk (s)		0.140	−0.785	1.065
Callaghan, 2005[39] (HD)	13 m walk (s)		−0.177	−1.103	0.749
Cetin, 2008[33]	50 m walk (time)		−0.110	−0.730	0.511
Laufer, 2005[40] (LD)	Timed Up and Go (s)		0.001	−0.465	0.468
Laufer, 2005[40] (HD)	Timed Up and Go (s)		−0.216	−0.703	0.272
Laufer, 2005[40] (LD)	Stair climbing (s)		−0.035	−0.501	0.432
Laufer, 2005[40] (HD)	Stair climbing (s)		−0.144	−0.631	0.343
Laufer, 2005[40] (LD)	Stair descending (s)		0.002	−0.464	0.468
Laufer, 2005[40] (HD)	Stair descending (s)		−0.153	−0.640	0.334
Laufer, 2005[40] (LD)	3 min walk (m)		0.021	−0.445	0.488
Laufer, 2005[40] (HD)	3 min walk (m)		0.227	−0.261	0.715
Rattanachaiyano, 2008[37]	100 m walk (m/min)	NS	–	–	–
Rattanachaiyano, 2008[37]	Stair negotiation (s)	NS	–	–	–
Quality of life					
Klaber-Moffett, 1996[41]	General Health questionnaire-30		0.293	−0.157	0.992

WOMAC – Western Ontario and McMaster Universities Osteoarthritis questionnaire; LD –low dose; HD – high dose; 6 MWT – 6 min walk test.
* *P* values reported when effect size could not be calculated.

meta-analysis[33,38,39]. Both studies[33,38] examined strength at the same three speeds (60, 120 and 180°/s), and similar positive results were obtained for all speeds. However, the analysis was conducted only for the 60°/s measure, which requires the greatest exertion. Overall analysis indicates a significant effect of SWD treatment on muscle strength [Effect size (CI) 0.465 (0.020, 0.910)] (Fig. 2).

One study[39] examined the effect of SWD treatment on joint inflammation following six treatments with either athermal SWD dosage (10 W) or mild thermal dosage (20 W), using radio-leucoscintigraphy. Their results showed no treatment effect on joint inflammation.

Range of motion (ROM)[39] was assessed by only one study employing mild thermal treatment, indicating no beneficial effect of SWD treatment on ROM.

Activity domain

Activity questionnaires. Six studies provided the results of self-report physical function questionnaires. Three studies using the WOMAC questionnaire[37,38,40], two of which were pooled[38,40], indicated no beneficial effects [Effect size −0.144, CI (−0.527, 0.240)] (Fig. 2). Rattanachaiyanont (2008)[37] did not supply enough data to be included in

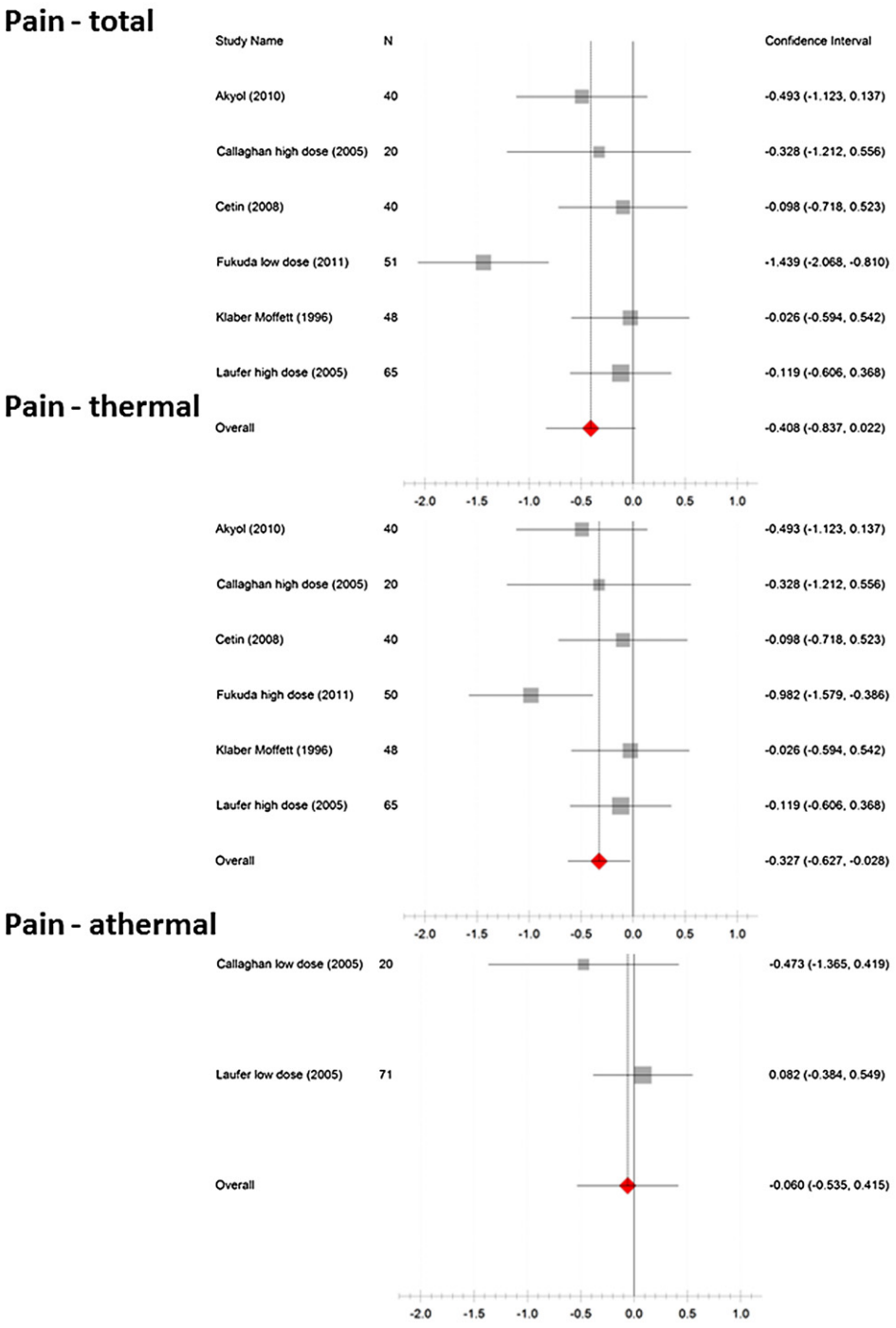

Fig. 1. Meta-analysis for pain reduction following SWD treatment.

the pooled analysis, but no significant differences were reported between the groups following treatment. One study[33] used the Lequesne Index to assess activity level, reporting greater improvement in the treated groups in comparison with the control group. One study[34] used the Knee Injury and OA Outcome Score (KOOS) to assess patient activity and found significant differences in the groups that received SWD treatment (low and high dose), as compared to the control or placebo groups (range $= P < 0.05 - P < 0.001$).

Gait performance. Five of the studies utilized gait performance tests to assess treatment effect. No pooled effects could be calculated due to differences in performance measures. No significant effects on walking capabilities were determined in these studies.

Quality of life. One study included self-report questionnaires in regard to quality of life[41] reporting no significant positive effect of SWD on quality of life compared with control groups.

Adverse events

One study described a few side effects that included mild pain, swelling and feeling of vasodilatation, these events were similar in

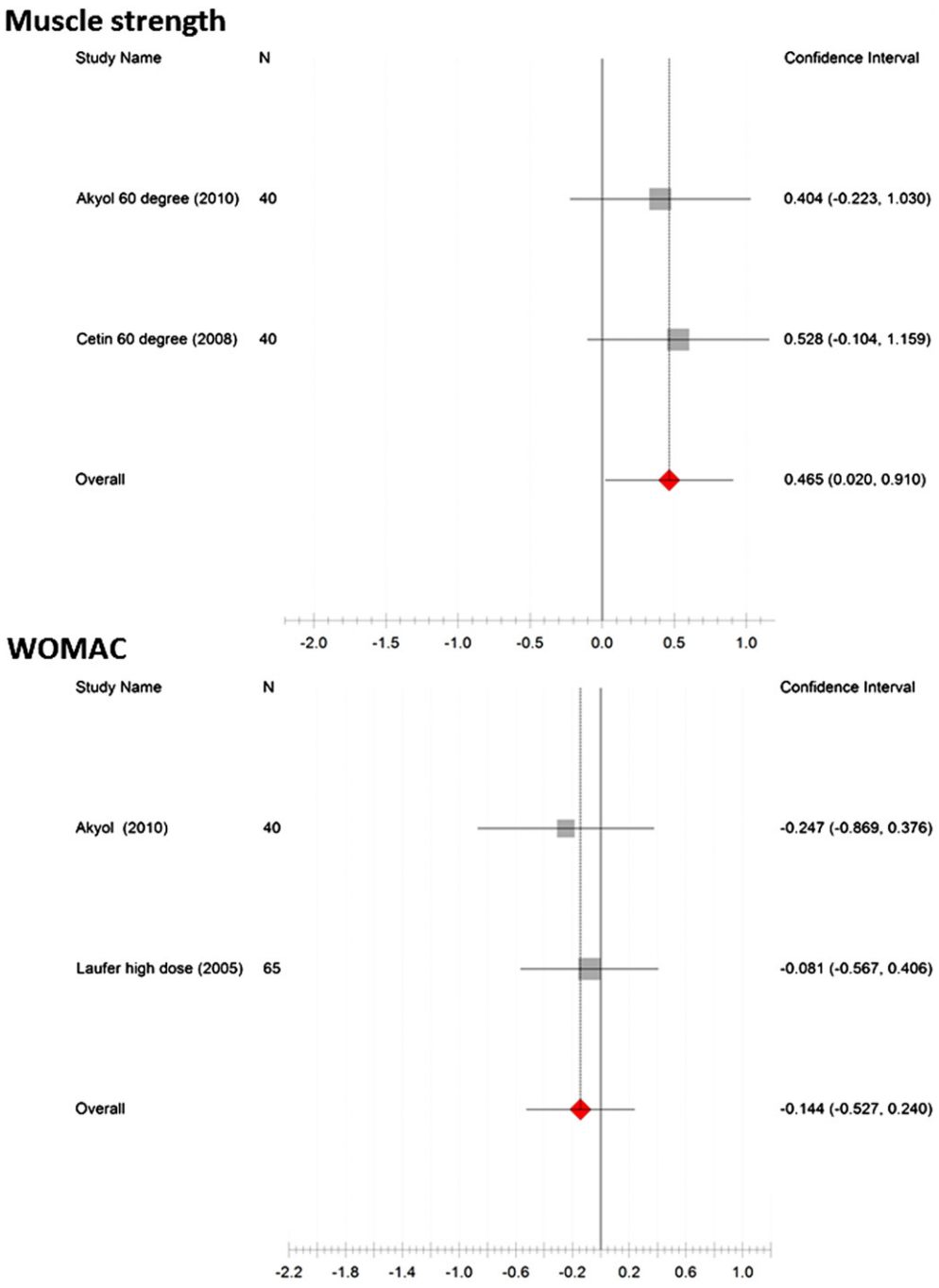

Fig. 2. Meta-analysis for muscle strength and WOMAC questionnaire following SWD treatment.

both the group receiving SWD treatment and the group receiving placebo SWD[37]. Therefore, they cannot be directly related to the SWD treatment. None of the remaining studies reported on whether or not there were any adverse events following treatment.

Discussion

A total of seven studies examining the effects of SWD treatment on the management of KOA were identified in this review. Due to the high variability in the outcome measures used in these studies, a meta-analysis was carried out only for pain, muscle strength, and functional abilities, as reported in the WOMAC questionnaire. This meta-analysis pointed to the strong possibility of an overall immediate effect following the completion of the last treatment session on pain (Table IV, Fig. 1). An additional separate analysis by thermal dose showed that the positive effect on pain perception is achieved only when the treatment involves at least some degree of thermal sensation. However, the analysis yielded no short-term follow-up effect[38,40,41], indicating that whatever benefit may be gained immediately post-treatment in terms of pain management is lost within a 9–12-week period.

The meta-analysis also demonstrated an immediate positive effect on muscle strength when SWD treatment was combined with an exercise program, in contrast to exercise alone (Table IV, Fig. 2). Knee pain associated with joint movement and muscle contraction may inhibit full muscle activation through central

mechanisms[42], which in turn may lead to weakness and disuse atrophy. Thus, pain in patients with KOA has been shown to correlate with quadriceps muscle weakness[43]. It is possible that the effects of the SWD treatment on knee pain may have contributed to the observed improvement in strength. However, these changes in pain and muscle strength did not carry over to the subjects' activity level, as assessed either by the WOMAC questionnaire or by the various gait performance measures (Table IV, Fig. 2).

In terms of self-reported functional ability, one study reported positive results using the KOOS questionnaire[36], while a second study using the Lequesne Index reported no effect on functional ability[33]. The remaining three studies[37,38,40] examining the effect on functional ability used the WOMAC questionnaire. However, only the two of them that could be pooled indicated no significant effect[38,40].

The variability in the treatment protocols makes it impossible to draw definitive conclusions about the factors determining the effectiveness of SWD treatment. To illustrate this point, we can consider the two studies which received the highest PEDro score (9/10)[36,37]. Whereas the study by Fukuda *et al.* (2011)[36], demonstrated significant improvements in both pain intensity and functional ability, no such effects were demonstrated by Rattanachaiyanont *et al.* (2008)[37]. Although several treatment parameters, such as mode of energy delivery and number of treatment sessions, were the same in both studies, there were at least two important factors which could have contributed to the conflicting results. First, treatment dose was almost four times higher in the study with the positive results (14.5 W vs 3.2 W). Second, while no other intervention was combined with the high-dose SWD treatment[36], in the second study, an exercise program was delivered to both the SWD and the control groups. Since research has repeatedly demonstrated the benefits of an exercise program in this population[44], one possible explanation for the differing results may be that the contribution of the SWD treatment was over-ridden by the effects of the exercise intervention. Yet, two other studies in our review also included an exercise intervention, with one demonstrating no benefit from adding SWD treatment to an exercise program[38], while the other demonstrated that the group receiving SWD treatment, hot packs and exercise had more improvement in pain level and muscle strength than the group receiving hot packs and exercise alone[33]. Thus, further research is necessary to determine what aspects of the treatment are crucial for its success.

One of our goals in this study was to examine whether inducing a thermal effect has a significant impact on the effectiveness of SWD treatment. However, deciding whether a thermal effect was induced in the reviewed articles turned out to be more complicated than expected. Only some of the studies reported whether or not a thermal sensation was induced[33,38,40], and others used different definitions. For example, Klaber Moffett *et al.* (1996)[41] employed a dose of 23 W and considered it sub-thermal, whereas Laufer *et al.* (2005)[40] reported that at 18 W, patients experienced a mild sensation of warmth. Therefore, in our sub-analysis, which attempted to differentiate studies by the degree of thermal sensation, we included in the athermal group only two studies with such a low dosage that a thermal effect could be definitely ruled out[37,40]. This separate analysis indicated the importance of at least some thermal effect for SWD treatment to be beneficial. Furthermore, it should be noted that no adverse effects were reported in any of the studies, indicating the safety of using SWD at a level inducing a mild thermal sensation in patients with KOA.

As stated above, a primary limitation of this review is that the meta-analysis for most outcome categories included only some of the studies, due to the high variability in the outcome measures used and to the lack of sufficient information necessary to conduct a meta-analysis. Future ability to conduct a more comprehensive meta-analysis would be enhanced by better standardization of the outcome measures used for the evaluation of patients with KOA at all levels of the International Classification of Functioning, Disability and Health (ICF), as well as provision of all the data necessary to conduct a meta-analysis (group means and SDs pre- and post-treatment). Inconsistencies in the reporting of the treatment dosage, high variability in the treatment protocols, and lack of long-term follow-up studies further limited our ability to reach more definitive conclusions. Furthermore, our review focused primarily on the effects of SWD treatment and did not attempt to examine its value or its cost effectiveness in comparison with other treatment modalities.

Practical and research implications

In conclusion, SWD treatment appears to be effective for decreasing pain and increasing muscle strength in patients with KOA. However, this effect is noticed primarily immediately post-treatment and is lost by 12 weeks following treatment. No definitive answers can be provided regarding the effects of SWD treatment on other impairments (e.g., joint inflammation) or on functional ability. The results indicate that athermal treatment is probably not beneficial. Since the more modern SWD equipment is menu driven, clinicians are encouraged to determine that the dose provided by the menu is sufficient to induce at least some thermal sensation.

More research, especially research using comparable samples, protocols and outcome measurements, is needed to evaluate the long-term effects of treatment and its cost effectiveness in patients with OA of the knee as well as OA of other joints.

Contribution of authors

All authors made substantial contributions to all three sections: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of the data, (2) the drafting of the article or revising it critically for important intellectual content and, (3) final approval of the version submitted.

Conflict of interest

None of the authors has competing interests.

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