Radiofrequency-based treatment in therapy-related clinical practice – a narrative review. Part II: chronic conditions

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Background: Radiofrequency (RF)-based electrophysical agents (EPAs) have been employed in therapy-related clinical practice for several decades. They are used to reduce pain and inflammation and promote tissue healing. Although deemed less popular in current therapy practice, surveys suggest that some of these EPAs are still used reasonably widely.

Objective: To review the evidence for the use of non-invasive low-frequency RFs (30 kHz - 30 MHz) for treating chronic therapy-related clinical conditions.

Major findings: All relevant peer-reviewed clinical studies published in English, concerning low-frequency RFs were sought. Identified literature was stratified as ‘acute’ and ‘chronic’ based on their clinical area. The studies on chronic conditions were reviewed for this paper and analysed to assess the volume and scope of current evidence. Out of 120 studies identified, 90 related to chronic conditions. The majority of them (82 studies) employed shortwave therapy (SWT) in continuous (CSWT) or pulsed (PSWT) modes. Only eight studies employed frequencies other than shortwave. Overall 67 studies investigated conditions relating to ‘pain and inflammation’, 16 to ‘tissue healing’ and 7 studies to other less reported conditions.

Conclusions: Evidence favouring and against RF-based EPAs is available. There is moderate evidence favouring the use of SWT (mainly PSWT) in knee osteoarthritis. Some evidence also exists for CSWT in chronic low back pain and PSWT for treating chronic wounds. Evidence for other conditions is insufficient and conflicting. A general lack of research emphasis in the non-shortwave RF band is evident. Further and wider research in this area is necessary.

Keywords: Chronic conditions, Clinical effects, Electrophysical agents, Non-invasive, Radiofrequency

Introduction

Therapeutic use of electrophysical energy has been well-established since the past century, making the treatment using electrophysical agents (EPAs) a key area in the realm of physiotherapy. Devices that employ radiofrequency electromagnetic field (RFEMF or simply RF) are a major component of EPAs, the use of which has been reported since the early decades of last century.3

The therapeutic effects of RF are mainly linked to their effects on pain relief and tissue repair.4,5 These effects may be achieved either through thermal or through non-thermal mechanisms, which are essentially dose dependent.5,6 At higher doses, the cardinal effects of RF are heat-related physiological changes triggered by a rise in the tissue temperature.7-10 At substantially lower doses of RF, a discernible rise in tissue temperature is not achieved,7,8 but rather the absorption of RF energy in tissues instigate a modulation in cellular activity and alter membrane transport.5 Although less well understood compared to the thermal effects, the non-thermal effects of RF and the mechanisms underpinning those effects have become more established in the recent years.11-13

Even though a key component among the EPAs, RF devices have become less popular lately. The RF frequency ranges presently used in therapy practice have become restricted largely to 30–30,000 kHz (30 MHz).14 The drop in popularity of RF-based EPAs has been reciprocated by the evolution and increased popularity of other forms of EPAs such as ultrasound, laser, transcutaneous electrical nerve stimulation (TENS) and interferential therapy (IFT).15-17 However, it may be argued that this swing towards other non-RF therapies may have been a...
fashionable shift rather than based on evidence per se. The fall in the use of RF-based EPAs is evidenced by the findings from recent surveys and reviews.\textsuperscript{14,18} That having been said, a recent audit in the UK has reported that RF-based EPAs such as the pulsed shortwave therapy (PSWT) is still used among about 11\% of outpatient clinics in the UK.\textsuperscript{17}

In part I\textsuperscript{19} of this review published by the same authors, the evidence for RF-based EPAs within the frequency range of 30 kHz - 30 MHz used in the treatment of acute therapy-related clinical conditions was presented. The objective of this paper (part II) is to review similar RF-based studies published to date on chronic conditions. In the current literature, apart from the reviews on varying specific conditions and specific RF energy types,\textsuperscript{6,20–25} no reviews covering the whole RF literature on chronic conditions could be identified. Hence, to our knowledge this is the first such attempt.

In part I,\textsuperscript{19} although beyond the primary remit of the review itself, relevant RF studies performed on laboratory animals were also covered in order to illustrate some key issues. However, unlike in acute conditions, the authors identified only one animal study\textsuperscript{26} that evaluated the effects of RF-based therapy that was directly relevant to chronic clinical conditions.

Vanharanta\textsuperscript{26} investigated the effect of continuous shortwave therapy (CSWT) on the joint mobility and radiographic changes during the development of osteoarthritis (OA) of the knee joint. The authors developed an experimental model of OA knee by periodically immobilising the knee joints of rabbits. They were then treated with CSWT (55 sessions in 11 weeks, 5 min per session) and compared with an identical group of non-treated control rabbits. The groups did not show any significant difference between them post treatment, in terms of joint mobility or radiological changes. A lack of further animal studies relevant to chronic conditions made it difficult to draw a definite comparison with human studies.

**Methods**

A detailed account of the methods adopted for this review has been reported previously in part I\textsuperscript{19} of this review. While the first part presented the overall search results and a review of the studies (published in English) on RF-based EPAs (30 kHz - 30 MHz) conducted on acute conditions, part II aimed to review the identified studies that were conducted on chronic conditions. As detailed in part I,\textsuperscript{19} the authors adopted an all-inclusive methodological approach for the purpose of this review; several examples of which are available in the literature.\textsuperscript{27–30} This approach is dissimilar to that of a systematic review and does not exclude studies based on their methodological design and/or quality as would be the norm in a systematic review.

The identified studies were stratified on the basis of the frequency of RF used (shortwave, non-shortwave), the study design (clinical trial, cohort study and case study) and their clinical application category [pain and inflammation, tissue healing, others (all other less reported conditions, e.g. – postoperative stiffness of joints)]. For the purpose of this review ‘chronic’ is considered as conditions older than six weeks. The authors understand that it is problematic to divide studies in to distinct acute and chronic categories as conditions may overlap to a varied extent. However, based on available examples\textsuperscript{31,32} the terms ‘acute’ and ‘chronic’ are not explicitly defined in the existing literature and any duration used for classifications have been based merely on personal opinion or anecdotal evidence.\textsuperscript{33}

The studies employing devices generating RF between 10 and 30 MHz were considered as shortwave studies, and those employing RF between 30 kHz and 10 MHz as non-shortwave studies. The methodological quality of the studies was screened using the Cochrane risk of bias assessment tool\textsuperscript{14} where appropriate and scored based on the checklist proposed by Downs and Black\textsuperscript{35} for randomised and non-randomised studies. The Downs and Black checklist is a valid tool\textsuperscript{36} containing 27 items concerning the quality of reporting, validity, bias and statistical power of the studies (maximum score of 32; higher the score better the quality). Over the years, several authors have used modified versions of this checklist, mainly by simplifying the ‘item 27’ (originally scored 0–5) that concerns statistical power.\textsuperscript{37,38} A similar modified version, scoring item 27 as either ‘zero’ (insufficient power) or ‘one’ (sufficient power) was used in this review. Hence, the maximum score that could be achieved by a study was 28.

**Results**

The flow of studies through the review is given in Fig. 1. Out of the 120 studies that were originally identified\textsuperscript{19} on the use of RF-based treatment in therapy practice, a total of 90 (75\%) studies investigated chronic conditions. Out of 90, there were 82 (91\%) shortwave studies and 8 (9\%) non-shortwave studies. Sixty-seven studies (74\%) were conducted on conditions relating to pain and inflammation and 16 (18\%) on conditions relating to tissue healing. A further seven studies (8\%) were classed as ‘others’ and related to a mixture of conditions that were reported relatively rarely (e.g. – postoperative stiffness of joints) (Fig. 2).

However, as identified, the authors recognise that it is challenging to classify studies into such distinct clinical categories stated above, given that they may overlap to a varied extent. Clearly there was potential overlap between studies (although more so for the acute studies) that considered pain and inflammation and that considered tissue healing. For the purpose of this review, the allocation of a particular paper into a group was based on the primary outcome(s) as identified by their authors. The full texts were available for all the studies discussed here except for three.\textsuperscript{39–41}
Discussion of results
All 90 studies that investigated the effects of RF on chronic clinical conditions are considered in detail in the following sections. The types of RF used, key characteristics including dose parameters (where reported) and the Downs and Black scores are given as tables in their respective sections.
Non-shortwave studies

Eight studies employed RF between the frequencies 30 kHz to 10 MHz for the management of chronic clinical conditions. Five of these studies were clinical trials, one cohort study and the remaining two were case studies. All eight studies reported conditions giving rise to pain and inflammation. Four were on OA of the knee joint, and one each on shoulder pain, temporo-mandibular joint (TMJ) pain and dysfunction, tendinopathy and other chronic pain conditions. The RF employed ranged from 250 to 500 kHz across all studies, except that by Takahashi and colleagues and the study by Nelson and colleagues where frequencies of 6000–8000 kHz (6–8 MHz) were used.

In one of the three randomised controlled trials (RCT) on OA knee, Nelson and colleagues reported a threefold improvement in VAS pain scores of 15 participants when treated with an active 6.8 MHz pulsed electromagnetic field device [80 (±9) sessions in 42 days, 15 min per session] compared with a placebo-treated group of 19 participants. Pain was the only outcome measured in this study, with no follow-up measurements beyond the immediate post treatment phase.

Similarly, Taverner and colleagues used 480 kHz transcutaneous pulsed radiofrequency (TPRF) therapy (single session for 10 min) against a placebo-TPRF on 52 participants (in two groups: active and placebo) awaiting total knee replacement. The study reported a statistically significant reduction in the pain (VAS) scores of active group participants at one and four weeks post treatment compared to the placebo group.

In another clinical trial, Alcidi and colleagues tested 500 kHz RF (five sessions in five days, 20 min per session) against TENS (50 Hz, 0.5-ms square waves for 20 min per session for five days) in 40 patients with OA knee (two groups of 20 each). The RF therapy induced a statistically significant and longer lasting reduction in pain compared to the TENS. However, while a 20-min treatment is appropriate for RF, it may be too short for TENS to be effective. Also, pain relief with TENS is shown to be prominent during the treatment as opposed to post-treatment.

All three RCTs were small with very short assessment periods and a limited number of outcome measures. None of them employed a true control group, nor did they account for confounding factors such as the use of medication.

Takahashi and colleagues conducted a pilot study on 12 patients presenting with OA knee using an 8 MHz RF applicator (three sessions in three weeks, 20 min per session). They demonstrated that 8 MHz RF can be used safely to induce hyperthermia inside the knee joints and obtain significant pain relief. The temperature inside the joint was recorded using an invasive metallic thermocouple that remained in situ for the duration of treatment. This could potentially have caused a direct heating of the thermocouple by the RF. It was not possible to determine from the paper whether the researchers had attempted to mediate this effect.

In a mixed case series by Balogh, TPRF therapy was applied to four patients who had suffered lumbar intervertebral disc and other injuries, using conventional TENS electrodes and a 500 kHz RF generator (10 min at 1–5 week intervals). Three out of the four patients treated reported significant improvement in self-reported pain and function. However, the treatment protocols were variable for each patient. In a similar study, Taverner and colleagues used RF at 480 kHz (single session of TPRF therapy for up to 12 min) to treat a cohort of 13 patients suffering from shoulder pain (15 shoulder joints). Two-thirds of their participants reported pain relief over three months.

Al-Badawi and colleagues achieved a significant reduction in TMJ pain and improvement in mandibular range of movement (ROM) in a double-blinded RCT with 40 participants (two groups of 20 each). The subjects were exposed to either 250 kHz pulsed RF (PRF) or placebo-PRF (six sessions in two weeks, 90 s per session), and then followed up for two weeks. The authors concluded that the overall beneficial effect of PRF on TMJ reported pain is a combination of a placebo and true therapeutic effects. This was difficult to be ascertained from these results though, as a true control group was not employed.

In another study by Costantino and colleagues, the immediate clinical effects on pain obtained by 448 kHz Capacitive Resistive Monopolar RF therapy were found to be significant yet equivalent to those obtained by cryoultrasound therapy and laser CO2 therapy. Forty-five athletes suffering from extensor tendinopathy (Achilles, patellar or elbow) were treated in 3 equal groups, each receiving 12 sessions of one of the 3 modalities (RF was given for 30 min, laser for 15 min and cryoultrasound for 20 min).

In summary, only a limited number of clinical studies have been published in the non-shortwave RF category. They suggest that RF energy below the frequency of 10 MHz might deliver appreciable therapeutic effects. However, these results should only be considered against their overall methodological quality, several of which were problematic. The paucity of controlled clinical studies and the poor overall methodological quality imply the need for substantially more research in this area. In addition, because of the varied nature of the frequency and dosage parameters used by their authors, any potential range of ideal doses could not be identified. The rationale for frequency and dose selection was also not reported (Table 1).

Shortwave studies

The authors identified 82 clinical studies relating to chronic conditions that employed RF within the shortwave frequency range of 10–30 MHz. All studies used...
### Table 1  Studies in the non-shortwave frequency range

| Study                  | Diagnostic category                     | Outcomes measured                      | Study type, sample size and number of groups | Type of RF used | RF dose parameters | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|------------------------|-----------------------------------------|----------------------------------------|----------------------------------------------|-----------------|--------------------|----------------------------------|------------------------------------------|----------------------------------|
| Al-Badawi et al.        | TMJ pain and dysfunction                | Pain and TMJ function                  | RCT; 40 subjects; 2 groups                    | PRF; 0.25 MHz   | NR | 600 | 6 (over 2 weeks); 90 s/session | Yes                                      | 21                              |
| Costantino et al.       | Tendinopathy                            | Pain                                   | Non-RCT; 45 subjects; 3 groups               | ORF; 0.42 MHz   | NR |                 | 12 (NR); 30 min/session           | Yes                                      | 15                              |
| Alcidi et al.           | OA knee                                 | Pain                                   | RCT; 42 subjects; 2 groups                    | CRF; 0.5 MHz    | ≤30 |                 | 5 (over 5 days); 20 min/session   | Yes                                      | 17                              |
| Taverner et al.         | OA knee                                 | Pain and function                       | RCT; 52 subjects; 2 groups                    | PRF; 0.48 MHz   | NR | 20,000 | Single session; 10 min/session | Yes                                      | 20                              |
| Nelson et al.           | OA knee                                 | Pain                                   | RCT; 34 subjects; 2 groups                    | CRF; 0.5 MHz    | ≤89 | 200 | (over 42 days); 15 min/session | Yes                                      | 25                              |
| Takahashi et al.        | OA knee                                 | Pain and function                       | Cohort; 11 subjects (12 knees); 1 group      | PRF; 8 MHz      | NR | 200 | 3 (over 3 weeks); 20 min/session | Yes                                      | 16                              |
| Balogh                 | Back pain, Multiple injuries            | Pain                                   | Case series; 4 subjects                      | PRF; 0.5 MHz    | NR | 20,000 | Numerous; 10 min/session | Yes                                      | 9                               |
| Taverner et al.         | Shoulder pain                           | Pain                                   | Retrospective audit; 13 subjects (15 shoulders) | PRF; 0.48 MHz   | NR | 20,000 | Single session; ≤12 min/session | Yes                                      | 9                               |

Notes: RCT – Randomised controlled trial; OA – Osteoarthritis; TMJ – Temporo-mandibular joint; RF – Radiofrequency; CRF – Continuous radiofrequency; PRF – Pulsed radiofrequency; PP – Peak power; PD – Pulse duration; PRR – Pulse repetition rate; MP – Mean power; NR – Not reported; NA – Not available to the authors; W – Watts; μs – Microseconds; pps – Pulses per second; min – Minutes.
devices delivering energy at the base shortwave frequency of 27.12 MHz either in the continuous (CSWT) or in the pulsed (PSWT) mode. Overall, 59 studies investigated conditions giving rise to pain and inflammation, 16 studies investigated tissue healing and the remaining 7 studies examined other less reported conditions such as postoperative stiffness of joints.

**Studies on pain and inflammation**

With 59 studies, this is the largest group in terms of the number of studies published. Almost half of them (28 studies) reported the effects of RF-based therapy on arthritis, predominantly OA of the knee joint.\(^{51-78}\) Twenty-seven of these studies were clinical trials and one cohort experimental study\(^{79}\) on the effect of CSWT on radio-sodium clearance from the knee joint. A further eight clinical trials\(^{41,79-85}\) and one cohort study\(^{86}\) investigated chronic low back pain (LBP), and one clinical trial\(^{79}\) and five case studies\(^{88-92}\) investigated various pelvic pain (gynaecological) conditions.

In addition, three clinical trials\(^{93-95}\) were identified on chronic neck disorders, one clinical trial\(^{86}\) and one case study\(^{96}\) on plantar fasciitis; and one clinical trial\(^{98}\) and one case study\(^{99}\) each were identified on chronic shoulder problems. Further, one clinical trial each on TMJ pain,\(^{100}\) trigger point pain\(^{101}\) and myofascial pain\(^{102}\); and one case study each on Herpes Zoster pain,\(^{103}\) heel neuroma,\(^{104}\) avascular necrosis of the femoral head\(^{105}\) and multiple cases of pain\(^{106}\) were also identified. Two recently published clinical trials\(^{107,108}\) on carpal tunnel syndrome (CTS) were also included.

**Arthritis**

As identified, the highest number of studies on the effects of SWT was reported on arthritis, primarily OA of the knee joint. Hamilton and colleagues\(^{41}\) in their study published in 1959 examined a heterogeneous mix of 62 patients suffering from either rheumatoid arthritis (RA; hands or knees) or OA knee. They reported that CSWT (12 sessions in 4 weeks, 20 min per session) improved outcomes of walking and stair climbing among the participants, but not significantly greater than other EPAs, or a placebo-CSWT.

An experimental study by Harris\(^{109}\) suggested that CSWT exposure (single session for 20 min) can improve circulation to the knee joints of people suffering from RA if the condition is quiescent whereas it can be counterproductive if the RA is active. In a later study, Wright\(^{110}\) gained better long-term improvement with CSWT (18 sessions in 6 weeks, 20 min per session) over placebo tablets and placebo injections among 38 patients with OA knee when treated in 3 different groups. Several studies followed till the early 1990s, where neither CSWT nor PSWT were found to be significantly better than any of the compared treatment methods.\(^{111-116}\) However, similar to the studies discussed above, none of these earlier trials employed a sufficiently robust methodology. Lack of adequate statistical power and absence of a true control group or long-term follow-ups were common to most of these studies. Nearly all the studies failed to report the SWT dosage parameters adequately (Table 2).

More recently, Klaber Moffett and colleagues\(^{117}\) agreed with the findings of the previous studies, as they found no significant differences between the active, control or placebo groups for self-reported pain and quality of life (QoL) measures of 92 subjects (nine sessions of PSWT in three weeks, 15 min per session). This was a well-designed RCT on patients suffering from hip and knee OA. Likewise, two very similar (small) clinical trials\(^{118,119}\) published in the last decade, which employed four different doses of PSWT (six and nine sessions, respectively, in two weeks; 20 min per session) between them in addition to a placebo dose, reported that there were no significant differences between any of the groups after the intervention.

In contrast, PSWT (10 sessions in two weeks, 15 min per session) was shown to improve pain and function at both low and high doses when combined with ultrasound therapy and progressive resistance exercises in the study by Tuzun and colleagues.\(^{120}\) However, both the groups (20 participants each) had a battery of interventions. In another study by Jan and colleagues,\(^{121}\) pain and synovial thickness (measured using ultrasonography) were lower in CSWT-treated groups (30 sessions in 8 weeks, 20 min per session) compared to a control group regardless of the NSAID consumption. The study had only limited sample (36 participants in three groups) and did not employ a randomised design. Also, the control group participants had significantly less pain at baseline compared to the CSWT group.

Further studies followed, comparing the effects of SWT to spa, ultrasound, ice or exercise therapies. All these studies reported SWT to be either less effective or no better than the comparison groups.\(^{122-129}\) Among these studies, only the trial conducted by Rattanachaiyanont and Kuptniratsaikul\(^{130}\) employed a well-designed methodology with adequate statistical power. However, even that study employed only female participants and the mean PSWT power dosage used was only 3.2 W, which might be too low for a chronic condition such as OA.

Among the recent studies, Cetin and colleagues\(^{131}\) suggested that PSWT (24 sessions in 8 weeks, 15 min per session) when used with isokinetic exercises reduces pain and augments function among women with OA knee. These findings were contradicted by Akyl and colleagues,\(^{132}\) who stated that the addition of CSWT (12 sessions in 4 weeks, 20 min per session) to an isokinetic exercise programme brought no further significant benefits in terms of pain and functional QoL. Both studies were small and the results only applied to women of menopausal age group. Unlike these CSWT studies, PSWT delivered at a mean power (MP) of 14.5 W (9 sessions in 3 weeks, either 19 min or 38 min per session) produced significantly better results
| Study                  | Diagnostic category | Outcomes measured                                      | Study type, sample size and number of groups | Type of RF used | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|-----------------------|---------------------|--------------------------------------------------------|---------------------------------------------|-----------------|---------------------------------|------------------------------------------|---------------------------------|
| Hamilton et al.        | RA hands/knee; OA knee | ROM and function                                       | Crossover RCT; 131 subjects; 4 groups       | CSWT            | 12 (over 4 weeks); 20 min/session | Yes                                      | 16                              |
| Harris                 | OA knee             | Local circulation (Radio-Sodium clearance)             | Experimental; 16 subjects; 2 groups         | CSWT            | Single session; 18 (over 6 weeks); 20 min/session | Yes/no                                   | 8                               |
| Wright                 | OA knee             | Pain, tenderness, walking time and analgesic intake    | RCT; 38 subjects (59 joints); 3 groups       | CSWT            | Yes                             | 13                                       |                                  |
| Valtosen and Alaranta  | OA knee/hip         | Level of improvement                                   | RCT; 160 subjects; 2 groups                 | CSWT            | 13-14 (over 5 weeks); 15-20 min/session | Yes                                      | 10                              |
| Clarke et al.          | OA knee             | Pain, stiffness, tenderness and swelling               | RCT; 48 subjects; 3 groups                  | CSWT            | 9 (over 3 weeks); NR            | No                                       | 18                              |
| Bansil and Joshi       | OA knee             | Pain and function                                      | RCT; 60 subjects (100 joints); 2 groups     | CSWT            | NR; 20 min/session              | No                                       | 12                              |
| Chamberlain et al.     | OA knee             | Pain, function, ROM, maximum weight lift and endurance | RCT; 42 subjects; 2 groups                  | CSWT            | Yes                             | 17                                       |                                  |
| Quirk et al.           | OA knee             | Pain, function, ROM, exercise endurance and knee girth | RCT; 38 subjects; 3 groups                  | CSWT            | 12 (over 4 weeks; NR)           | Yes                                      | 17                              |
| Svarcova et al.        | OA knee/hip         | Pain and 'therapeutic effect'                          | Non-RCT; 180 subjects; 3 groups             | PSWT            | 10 (over 3 weeks); 4 min/session | Yes                                      | 15                              |
| Jan and Lai            | OA knee             | Function and muscle torque                              | RCT; 61 subjects (94 joints); 4 groups       | CSWT            | 24-69 (over 6–18 weeks); 20 min/session | Yes                                      | 15                              |
| Sewell et al.          | RA knee             | Pain, swelling and function                            | RCT; 81 subjects; 2 groups                  | PSWT            | 8 (over 4 weeks); 10 min/session | No                                       | NA                              |
| (Abstract only)        | OA knee             | Pain and function                                      | RCT; 92 subjects; 3 groups                  | PSWT            | 9 (over 3 weeks); 15 min/session | No                                       | 19                              |
| Klaber Moffett et al.  | OA knee             | Pain, function, ROM and muscle strength                | RCT; 40 subjects; 2 groups                  | PSWT            | 10 (over 2 weeks); 15 min/session | Yes                                      | 15                              |
| Tuzun et al.           | OA knee             | Pain, function, ROM and muscle strength                | RCT; 27 subjects; 3 groups                  | PSWT            | 5 (over 2 weeks); 20 min/session | No                                       | 22                              |
| Callaghan et al.       | OA knee             | Pain, function, ROM and muscle strength                | Non-RCT; 103 subjects; 3 groups             | PSWT            | 20 min/session                  | No                                       | 19                              |
| Laufer et al.          | OA knee             | Pain, function, timed walk and stair use               | Non-RCT; 30 subjects (44 joints); 3 groups  | CSWT            | 30 (over ≥8 weeks); 20 min/session | Yes                                      | 17                              |
| Jan et al.             | OA knee             | Pain and synovial sac thickness                        | RCT; 74 subjects; 3 groups                  | CSWT            | 15 min/session                  | No                                       | 20                              |
| Cantarini et al.       | OA knee             | Pain, function, QOL and analgesic intake               | RCT; 24 subjects; 2 groups                  | CSWT            | 6-10 (over 2 weeks); a20 min/session | Yes                                      | 8                               |
| Manhal et al.          | OA knee             | Pain, deformity and muscle wasting                     | RCT; 25 subjects; 3 groups                  | CSWT            | 10 (over 5 weeks); No           | No                                       | 16                              |
| Silva et al.           | OA knee             | Pain, function, ROM and muscle strength                | RCT; 100 subjects (200 joints); 5 groups    | CSWT            | 24 (over 8 weeks); 15 min/session | Yes                                      | 20                              |

Continued
Table 2 Continued

| Study type, sample size and number of groups | Diagnostic category | Outcomes measured | Type of RF used | Number and duration of sessions | Number of sessions | Average PSWT power dose (W) (PP) PD (μs) PRR (pps) MP (W) | Did RF improve the outcomes significantly? |
|---------------------------------------------|---------------------|-------------------|----------------|---------------------------------|-------------------|-------------------------------------------------|------------------------------------------|
| Ovanessian et al.72  | OA knee  | Pain, function, QoL and ROM | CSWT | NR  | 10 (over 2 weeks); 20 min/session | Yes  | 23 |
| Teslim and colleagues77  | OA knee  | Pain and ROM | CSWT | NR  | 8 (over 4 weeks); 20 min/session | Yes  | 23 |
| Rattanachaiyanont and Kuptniratsaikul73  | OA knee  | Pain and function, with no significant differences | PSWT | NR  | 12 (over 4 weeks); 20 min/session | No  | 21 |
| Akyol et al.76  | OA knee  | Pain, function and ROM | CSWT | NR  | 10 (over 4 weeks); 20 min/session | Yes  | 25 |
| Fukuda et al.71,75  | OA knee  | Pain, function and QoL | PSWT | NR  | 9 (over 3 weeks); 19–38 min/session | Yes  | 21 |
| Ovanessian et al.72  | OA knee  | Pain, function, QoL and ROM | CSWT | NR  | 10 (over 2 weeks); 20 min/session | Yes  | 21 |
| Consistent with the above results, Fukuda and colleagues published two well-designed RCTs71,75 on the effects of PSWT on pain and function in women suffering from OA knee. Two doses of PSWT delivering either 17 or 33 kJ of total energy (9 sessions in 3 weeks, 19 or 38 min per session, respectively) were tested against a placebo group and a control group. Both studies suggested that PSWT produced significantly better clinical outcomes over placebo and control. However, there was no significant difference between the effects produced by the two experimental doses.

In another well-designed multi-centre RCT published recently by Atamaz and colleagues,76 PSWT (15 sessions in 3 weeks, 20 min per session) was reported to have significantly improved the pain outcomes over a placebo resulting in lower consumption of NSAIDs. The study also had TENS and IFT treated groups, both of which produced similar results over the placebo. There were no significant differences between the three treatment modalities. However, it is not known whether these effects were sustained, as there were no follow-up assessments. Interestingly, similar to the Rattanachaiyanont and Kuptniratsaikul73 study, the mean PSWT power dose employed was only 3.2 W, which might be too low for a chronic condition such as OA.

Among the two most recent studies identified, Boyaci and colleagues78 compared the effects of CSWT (10 sessions in 2 weeks, 20 min per session) with those of ultrasound and ketoprofen phonophoresis among 101 women (in three groups) with OA knee. It was reported that all three groups improved significantly in terms of self-reported pain and function, with no significant differences between the groups. In the second smaller pilot study by Teslim and colleagues,77 CSWT (eight sessions in four weeks, 20 min per session) was reported to be more effective in improving the knee ROM and pain compared to PSWT (eight sessions in four weeks, 20 min per session) among 24 participants with OA knee (2 groups of 12 each). There were no follow-up assessments in either study and neither did they feature control or placebo groups.

Although several of the earlier arthritis studies discussed above lacked robust methodological quality and gave conflicting results, many of the more recently published studies have supported the use of SWT (mainly PSWT) in the management of OA knee. Where reported, the dosage parameters and the overall duration of intervention varied greatly among the studies and the rationale for dose selection was not stated. The durations of intervention varied between single sessions to several weeks in most studies, with an average of 3–6 weeks. No CSWT studies have reported their actual doses employed, apart from merely stating the (subjective) thermal levels of treatment.

For OA knee, based on the evidence a mean PSWT power dose at or above 14.5 W, 8–12 sessions over...
4–6 weeks and 15–20 min per session may be necessary for the treatment to be beneficial.

Some of the studies considered here were also covered by systematic reviews published previously. The reader is advised to refer to those reviews for additional information.

**Low back pain**
Among the nine studies on chronic LBP, two large multi-group trials by Gibson and colleagues (12 CSWT sessions in 4 weeks, session duration not reported) and Sweetman and colleagues (six CSWT sessions in two weeks, 20 min per session) reported that CSWT has not been particularly beneficial over exercises, traction, osteopathy or placebo-CSWT. Conversely, two other small clinical trials by Davies and colleagues (CSWT dose parameters not reported) and Wagstaff and colleagues (six PSWT sessions in three weeks, 15 min per session) recommended that the effects of both pulsed and continuous SWT were significant in relation to pain relief. The latter also suggested that adding an exercise regime to the intervention, or using dissimilar shortwave pulse patterns did not change the outcome.

Among the later studies, Kerem and Yigiter studied 60 subjects (3 groups of 20 participants each) and recommended that both CSWT and PSWT (10 sessions of 20 min each) effectively reduced LBP although the effects of PSWT were superior. Similarly, three studies published by the same research group (Shakoor and colleagues) reported that CSWT (18 sessions in 6 weeks, 15 min per session) significantly improved the efficacy of management of chronic LBP. In another recent study by Kim and colleagues, CSWT (single session of treatment, duration not reported) was found to significantly complement manual therapy (nerve mobilisation) in a group of 11 patients with LBP, compared to a similar group treated by manual therapy alone.

The cohort of studies examining the effects of SWT on LBP was much smaller when compared to that of OA knee. The majority of studies employed CSWT and generally favoured its use for the management of LBP. The overall methodological quality of the studies remained low. Grouping issues, lack of follow-up assessments and poor baseline equivalence between the study groups were apparent. Similar to the studies on several other conditions discussed here, the dosage parameters were not fully reported and they remained varied where reported. The rationale for dose selection was not stated, which combined with the lack of dose specific information made it impossible to draw any dose related conclusions. The duration of intervention ranged between single sessions to six weeks in most studies, with an average duration of 3–5 weeks.

**Pelvic pain**
Studies on pelvic conditions were published as early as 1938, when Waters reported positive responses to CSWT. (up to 36 sessions delivered) from 120 gynaecological patients. Subsequently, Burgess reported a study of 50 cases of pelvic sepsis treated by CSWT (12–16 sessions in 4–6 weeks, 30 min per session) to obtain intra-vaginal hyperthermia. Patients with gross chronic inflammation appeared to respond satisfactorily to the RF treatment. Later studies included a 71-patient case series of gynaecology patients by Punnonen and colleagues (10–15 PSWT sessions on alternate days) and two small case studies by Balogun and Okonofua (9 CSWT sessions in 3–4 weeks, 25–60 min per session) and Lamina and Hanif (15 CSWT sessions in 30 days, 30 min per session). All these studies suggested that SWT may be an effective treatment modality for pelvic pain arising from gynaecological conditions.

Only one among the six identified studies in this category was an RCT, where Lamina and colleagues examined 32 subjects (in three groups) suffering from pelvic inflammatory disease and suggested that CSWT (15 sessions in 30 days, 20 min per session) showed significant benefit over analgesics and a placebo in reducing pain. This study was low in statistical power and lacked follow-up assessment.

On the whole, with only one RCT identified there is insufficient robust evidence to support the use of SWT for managing chronic pelvic pain secondary to gynaecological disorders.

**Neck pain**
Three studies (well-designed RCTs) were identified, which studied the effects of PSWT on chronic neck pain. Among them, two studies were based on the same data. In the first of the three studies, Foley-Nolan and colleagues demonstrated that PSWT therapy gave better outcomes of pain and neck ROM compared to a placebo. The active group participants were a PSWT generating soft cervical collar eight hours daily for six weeks. This was a small study with 20 participants (divided in two groups), and without any long-term follow-up assessments.

In a more recent and much larger pragmatic RCT, Dziedzic and colleagues studied 350 patients in three groups (manual therapy, PSWT and control) over 32 weeks (8 PSWT sessions in 6 weeks, 15–20 min per session). The study suggested that the addition of either manual therapy or PSWT to ‘advice and exercise’ did not improve the outcomes. However, being a pragmatic trial, a potential drawback of this study was that it involved 55 different therapists to deliver the intervention, potentially giving rise to reliability issues. Also, the treatment dosage was not fixed across the population, the decision being left to the treating clinician. In a later publication, Lewis and colleagues evaluated the economic outcomes of this study and concluded that the cost-effective intervention was likely to be advice and exercise or manual therapy depending on the economic perspective and preferred outcome, but not PSWT.
Similar to the conditions on pelvic pain, there is insufficient evidence for the use of SWT in the management of chronic neck pain. Although the reported studies were of good methodological quality, no further studies have been identified.

Other conditions with pain and inflammation

Two recent studies were identified on the use of portable PSWT devices in the management of plantar fasciitis.96,97 Brook and colleagues96 studied 70 patients placed in two groups (42 active, 28 placebo) and demonstrated a significant reduction of morning pain in the actively treated group who wore a PSWT device during the night for 7 days. However, the study lacked sufficient statistical power and did not perform any follow-up assessments. Similar results were also achieved by Michel in a brief case report with six participants.97

Apart from plantar fasciitis, two studies were also identified on the use of SWT in chronic shoulder pain. In a case study published by Ginsberg,99 PSWT (10 min to the shoulder and 10 min to the liver) was shown to produce ‘impressive clinical results’ in the opinion of the author. The study involved 94 patients suffering from shoulder bursitis with calcification. In the second study, which was a more recent clinical trial,98 40 cases of shoulder adhesive capsulitis improved significantly with CSWT (10 sessions in 2 weeks, 20 min per session), although it was found to be less effective compared to manual therapy (delivered according to the ‘Cyriax approach’).

In two recently published studies,107 both CSWT and PSWT (15 sessions in 3 weeks, 20 min per session) were reported to be effective in the management of mild and moderate CTS compared to a placebo. Significant improvements were gained in pain, hand function and the electrophysiological measurements. In addition, CSWT was reported to be more effective in reducing symptom severity than either PSWT or placebo.

Among other less reported conditions, Gray and colleagues106 published a clinical trial on 176 patients with TMJ pain, comparing four active interventions (CSWT, PSWT, laser and ultrasound; 12 sessions in 4 weeks). The CSWT was applied for 10 min per session and PSWT 20 min per session. All groups reported significant improvement, but without any significant difference between the groups. Myofascial pain (TMJ-related) was shown to improve markedly by CSWT in another trial with 120 patients (three groups: drug therapy, CSWT and ultrasound; 14 sessions of CSWT in 2 weeks, 20 min per session). Nonetheless, the effects of ultrasound therapy were superior to that of CSWT. In another brief study,101 on the management of trigger point pain, a single session of CSWT (20 min) was found to be more effective than a similar single session treatment with moist heat for reducing tenderness. The result, however, was not statistically significant.

In case studies, SWT was found to be effective in the management of pain associated with Herpes Zoster103 (daily CSWT sessions of 20 min each), heel neuroma104 (6–12 PSWT sessions in 3–4 weeks, 10–15 min per session), and avascular necrosis of the femoral head107 (PSWT for varying durations). No statistical reporting was done by any of these case studies.

Overall, there is insufficient robust evidence to support the use of SWT in the management of any of the conditions discussed in this section (Table 3).

Studies on tissue healing

Out of the 16 studies identified in this category, 14 studies (88%) investigated the effects of RF on chronic wounds or chronic ulcers,110–123 and two on bone healing.90,124 As identified, all studies employed devices delivering RF energy in pulsed mode at the base shortwave frequency of 27.12 MHz (PSWT). Nine of these were case studies,115–122 one was a cohort study110 and a further four were clinical trials.111–114 The case studies reported the effectiveness of PSWT treatment of diabetic foot ulcers,115,119,123 chronic pressure ulcers,116,122 chronic lower extremity wounds117,120 and venous/microvascular stasis ulcers.118,121

In a cohort of 22 patients with pressure ulcers, Itoh and colleagues113 achieved faster healing when treated by PSWT (30 min twice daily) in addition to conventional treatment. Stage II ulcers, which remained unhealed after 3–12 weeks healed completely in 2.33 weeks on average and stage III ulcers unhealed after 8–168 weeks healed completely in 8.85 weeks on average. There was no control group in this study and any statistical analysis of the data was not reported.

Among the clinical trials, Comorosan and colleagues111 treated 30 elderly patients with pressure ulcers in three separate groups, one of which received PSWT (30 min twice daily locally, 20 min once daily to the liver). The PSWT group showed much faster improvement (Stage II ulcers healed in 3.28 weeks and Stage III ulcers healed in 4.87 weeks on average) compared to the placebo and control groups that showed poor or no improvement. This trial had numerous methodological limitations including a low sample and absence of validated outcome measures and statistical analysis.

In contrast, Salzberg and colleagues112 and Kloth and colleagues114 employed improved methods in their studies although the latter had a fairly small sample. In the first study, a 12-week PSWT treatment programme was found to significantly accelerate wound healing in spinal cord injured patients with stage II and stage III pressure ulcers.112 In the second study, four weeks of PSWT (20 sessions, 30 min per session) achieved significantly higher (64 ± 15%) healing rate compared to a placebo (−8 ± 24%).114

In another small trial, 20 non-ambulatory male patients were treated for 4 weeks with four different PSWT pulse and field protocols (20 sessions, 20 min per session) in...
Table 3 Shortwave studies on pain and inflammation (all others excluding arthritis)

| Study | Diagnostic category | Outcomes measured | Study type, sample size and number of groups | Type of RF used | RF dose parameters | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|-------|---------------------|-------------------|---------------------------------------------|----------------|-------------------|------------------------------|------------------------------------------|-------------------------------------|
| Incebiyik et al. | Carpal tunnel syndrome | Pain and function | RCT; 31 subjects (58 joints); 2 groups | CSWT | CSWT | 300/600 4000 200/46 240/1.10 | Yes | 17 |
| Shakoor et al. | LBP | Pain | RCT; 102 subjects; 2 groups | CSWT | NA | 15 (over 3 weeks); NA | Yes | NA |
| Ahmed et al. | LBP | Pain, tenderness and analgesic intake | RCT; 97 subjects; 2 groups | CSWT | NR | 18 (over 6 weeks); Yes | 17 |
| Davies et al. | LBP | Pain and flexion ROM | RCT; 43 subjects; 3 groups | CSWT | NR | 109 (over 6 weeks); 15 min/session | Yes | 17 |
| Gibson et al. | LBP | Pain and flexion ROM | RCT; 109 subjects; 3 groups | CSWT | NR | 12 (over 6 weeks); NR | Yes | 17 |
| Kerem and Yigiter | LBP | Pain, ROM and muscle strength | Non-RCT (?); 60 subjects; 3 groups | CSWT/PSWT | NR | 300/600 4000 200/46 240/1.10 | Yes | 17 |
| Sweetman et al. | LBP | Clinical outcome | RCT; 400 subjects; 2 groups | CSWT | NR | 6 (over 2 weeks); 30 min/session | No | 20 |
| Waggstaff et al. | LBP | Pain | RCT; 23 subjects; 3 groups | CSWT/PSWT | NR | 300/600 4000 200/82 23.4/23.2 | Yes | 14 |
| Kim et al. | LBP | Pain, function and knee extensor strength | RCT; 22 subjects; 2 groups | CSWT | NR | 12–16 (over ≤6 weeks); 30 min/session | Yes | 10 |
| Shakoor et al. | LBP | Pain and tenderness | Cohort study; 50 subjects; 1 group | CSWT | NR | 15 min/session | Yes | 14 |
| Lamina et al. | PID | Pain and inflammation | RCT; 32 subjects; 3 groups | CSWT | NR | 15 min/session; Single session; Yes | 17 |
| Balogun and Okonofua | PID | Pain | Case study; 1 subject | CSWT | NR | 15 min/session | Yes | 7 |
| Burgess | Mixed cases of pelvic sepsis | Pain and treatment outcome | Case series; 50 subjects | CSWT | NR | 12–16 (over ≤6 weeks); Yes | 4 |
| Lamina and Hanri | PID | Pain | Case series; 3 subjects | CSWT | NR | 15 min/session | Yes | 9 |
| Punnonen et al. | Mixed gynecology and obstetrics cases | Pain and treatment outcome | Case series; 71 subjects | PSWT | 300 NR 62 NR | Yes | 6 |

Continued
Table 3 Continued

| Study | Diagnostic category | Outcomes measured | Study type, sample size and number of groups | Type of RF used | RF dose parameters | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|-------|---------------------|-------------------|---------------------------------------------|-----------------|-------------------|--------------------------------|-----------------------------------------|-----------------------------------|
| Waters et al. | Mixed gynaecology and obstetrics cases | Pain and treatment outcome | Case series; 120 subjects | CSWT | NR | Pain | ≤36 (over ≤4 weeks); ≤15 min/session | Yes | 6 |
| Dziedzic et al. | Non-specific neck pain | Pain and function | RCT; 350 subjects; 3 groups | PSWT | NR | NR | 8 (over 6 weeks); 20 min/session | Yes | 22 |
| Foley-Nolan et al. | Neck pain | Pain and ROM | RCT; 20 subjects; 2 groups | PSWT | NR | 60 | 450 | 0.0015/cm² | Yes | 19 |
| Lewis et al. | Non-specific neck pain | Cost effectiveness | RCT; 350 subjects; 3 groups | PSWT | NR | NR | 7.4 | 8 (over 6 weeks); 20 min/session | Yes | 22 |
| Brook et al. | Plantar fasciitis | Morning pain | RCT; 70 subjects; 2 groups | PSWT | 98 x 10⁻⁴ | 100 | 1000 | 98 x 10⁻⁶ | Yes, but not cost effective | 24 |
| Michel | Plantar fasciitis | Pain and tenderness | Case series; 6 subjects | PSWT | NR | NR | NR | NR | Yes | 7 |
| Guer-Uysal and Kozanoglu | Adhesive capsulitis shoulder | Recovery rate, pain and ROM | RCT; 40 subjects; 2 groups | CSWT | | | | | Yes | 20 |
| Ginsberg | Calcified bursitis shoulder | Pain, ‘clinical signs’ and mandibular ROM | Case series; 94 subjects | PSWT | 1025/NR | 65 | 600/400 | 40/NR | Yes | 7 |
| Gray et al. | TMJ pain and dysfunction | Calcium absorption rate | RCT; 176 subjects; 5 groups | CSWT/PSWT | NR | 60 | 100 | NR | Yes | 15 |
| McCray and Patton | Trigger points | Pain, tenderness, TMJ noises and ROM | RCT; 19 subjects; 2 groups | PSWT | NR | NR | NR | NR | Single session; 20 min/session | 14 |
| Talaat et al. | Myofascial pain syndrome | Myofascial pain | RCT; 120 subjects; 3 groups | CSWT | NR | NR | NR | NR | Yes | 10 |
| Alberry et al. | Herpes zoster pain | Pain | Case series; 97 subjects | CSWT | NR | NR | NR | NR | Yes | 7 |
| Shandies et al. | Heel neuroma | Pain | Case series; 317 subjects | PSWT | 975/NR | 65 | 600/400 | 38/NR | Yes | 4 |
| Oke et al. | AVN femoral head | Pain and ROM | Case series; 4 subjects | PSWT | 200 | 400 | 400 | 32 | Yes | 7 |
| Taylor | Abcess, neuralgia, neuritis | Pain | Case series; 3 subjects | CSWT | NR | NR | NR | NR | Yes | 4 |
| Boyaci et al. | Carpal tunnel syndrome | Pain, function and nerve conduction | RCT; 30 subjects (55 points); 3 groups | CSWT/PSWT | NR | 400 | 82 | NR | 15 (over 3 weeks); 20 min/session | Yes | 24 |

RCT – Randomised controlled trial; LBP – Low back pain; PID – Pelvic inflammatory disease; AVN – Avascular necrosis; TMJ – Temporo-mandibular Joint; ROM – Range of movement; RF – Radiofrequency; CSWT – Continuous shortwave therapy; PSWT – Pulsed shortwave therapy; PP – Peak power; PD – Pulse duration; PRR – Pulse repetition rate; MP – Mean power; NR – Not reported; NA – Not available to the authors; W – Watts; μs – Microseconds; pps – Pulses per second; min – Minutes.
| Study                        | Diagnostic category                                      | Outcomes measured                     | Study type, sample size and number of groups | Type of RF used | RF dose parameters | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|------------------------------|----------------------------------------------------------|---------------------------------------|---------------------------------------------|-----------------|-------------------|----------------------------------|-------------------------------------------|-----------------------------------|
| Comorosan et al.[1]          | Post-traumatic Algoneurodystrophies                      | NA                                    | Cohort; 45 subjects                         | PSWT            | NA                | NA; NA                          | Yes                                       | NA                                |
| Itoh et al.[10]              | Pressure ulcers                                          | Ulcer size and healing rate           | Cohort; 20 subjects (22 ulcers); 1 group    | PSWT            | 975               | 65                 | 600                          | 38             | ≤308 (over ≤22 weeks); Yes                     | 13                                |
| Comorosan et al.[11]         | Pressure ulcers                                          | Ulcer size and healing rate           | RCT; 30 subjects; 3 groups                  | PSWT            | 975/NR            | 65                 | 600/400                       | 38/NR          | ≤112 (over ≥8 weeks); ≤30 min/session; Yes      | 15                                |
| Salzberg et al.[12]          | Pressure ulcers                                          | Ulcer size and healing rate           | RCT; 30 subjects; 2 groups                  | PSWT            | NR                | NR                 | NR                           | NR             | NR (over ≥12 weeks); ≤30 min/session; Yes        | 20                                |
| Seabone et al.[13]           | Pressure ulcers                                          | Ulcer size                            | RCT; 20 subjects; 4 groups                  | PSWT            | 700               | 400                | 110/20       | 30.8/5.6 | 20 (over 2 weeks); ≤30 min/session; Yes               | 23                                |
| Klofn et al.[14]             | Pressure ulcers                                          | Ulcer size                            | RCT; 10 subjects; 2 groups                  | PSWT            | NR                | 65                 | 600                          | NR             | 20 (over 4 weeks); ≤30 min/session; Yes               | 20                                |
| Larsen and Overstreet[15]    | Diabetic foot ulcers                                    | Ulcer size and healing rate           | Case series; 2 subjects                     | PSWT            | NR                | 42                 | 1000                         | NR             | NR (over 16–17 weeks); ≤30 min/session; Yes          | 9                                 |
| Porreca and Giordano-Jablon[16] | Pressure ulcers                                      | Ulcer size                            | Case study; 1 subject                       | PSWT            | NR                | 42                 | 1000                         | NR             | 60–420 (1–7 months); ≤30 min/session; Yes           | 7                                 |
| Frykberg et al.[17]          | Pressure, diabet ic and venous ulcers                    | Ulcer size                            | Case series; 4 subjects                     | PSWT            | NR                | 42                 | 1000                         | NR             | 120–240 (over 2–4 months); ≤30 min/session; Yes     | 9                                 |
| Fletcher[18]                 | Venous ulcer                                             | Pain and ulcer size                    | Case study; 1 subject                       | PSWT            | NR                | 42                 | 1000                         | NR             | ≤150 (over 6 weeks); ≤30 min/session; Yes            | 7                                 |
| Frykberg et al.[19]          | Diabetic foot ulcers                                    | Ulcer size                            | Case study; 1 subject                       | PSWT            | NR                | 42                 | 1000                         | NR             | ≤200 (over 14 weeks); ≤30 min/session; Yes           | 7                                 |
| Frykberg et al.[20]          | Pressure, diabet ic and venous ulcers                    | Ulcer size                            | Cohort (retrospective audit); 113 subjects; 1 group | PSWT            | NR                | 42                 | 1000                         | NR             | 56 (over 4 weeks); ≤30 min/session; Yes              | 14                                |
| Maier[21]                    | Cutaneous ulcers of the ankle                           | Ulcer size                            | Case series; 2 subjects                     | PSWT            | NR                | 42                 | 1000                         | NR             | 42–392 (over 3–28 weeks); ≤30 min/session; Yes      | 8                                 |
| Conner-Kerr and Isenberg[22] | Pressure ulcers                                          | Ulcer size and healing rate           | Cohort (retrospective audit); 89 subjects; 1 group | PSWT            | NR                | 42                 | 1000                         | NR             | 56 (over 4 weeks); ≤30 min/session; Yes              | 14                                |
| Rawe and Vlahovic[23]        | Diabetic foot ulcers and venous ulcer                    | Ulcer size and pain                    | Case series; 4 subjects                     | PSWT            | NR                | 42                 | 1000                         | NR             | 21–42 (over 3–6 weeks); ≤6–8 h/session; Yes         | 9                                 |
| Sharp and Lightwood[24]      | Fracture non/ delayed union                              | Healing rate                          | Case series; 16 subjects                    | PSWT            | NR                | NR                 | NR                          | NR             | NR (over 11–54 weeks); Yes                         | 6                                 |

Notes: RCT – Randomised controlled trial; RF – Radiofrequency; CSWT – Continuous shortwave therapy; PSWT – Pulsed shortwave therapy; PP – Peak power; PD – Pulse duration; PRR – Pulse repetition rate; MP – Mean power; NR – Not reported; NA – Not available to the authors; W – Watts; μs – Microseconds; pps – Pulses per second; min – Minutes.
Table 5 Studies on other less reported conditions

| Study                                      | Diagnostic category                                      | Outcomes measured                                                                 | Study type, sample size and number of groups | Type of RF used | RF dose parameters | Number and duration of sessions | Did RF improve the outcomes significantly? | Downs and Black score (out of 28) |
|--------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------|-----------------|-------------------|---------------------------------|------------------------------------------|-----------------------------------|
| Draper et al.125                          | Post-traumatic (fracture) stiffness (elbow)              | ROM                                                                                 | Case study; 1 subject                       | PSWT            | 150 400 800 48    | 6 (over 2 weeks); 20 min/session | Yes                                       | 11                                |
| Seiger and Draper126                       | Post-traumatic (fracture) stiffness (ankle)              | ROM                                                                                 | Case series; 4 subjects                     | PSWT            | 150 400 800 48    | 8–13 (over 3–5 weeks); 20 min/session | Yes                                       | 12                                |
| Draper and VanPatten57                     | Post-surgical stiffness (knee)                           | ROM                                                                                 | Case study; 1 subject                       | CSWT            | 35                | 6 (over 2 weeks); 20 min/session | Yes                                       | 11                                |
| Johnson and Draper128                      | Fibrosis and adhesions post breast cancer                | ROM                                                                                 | Case study; 1 subject                       | PSWT            | 150 400 800 48    | 12–15 (over 6 weeks); 20 min/session | Yes                                       | 11                                |
| Draper129                                  | Post-traumatic/Post-surgical stiffness (elbow)           | ROM                                                                                 | Case series; 6 subjects                     | PSWT            | 150 400 800 48    | 4–6 (over 2 weeks); 20 min/session | Yes                                       | 12                                |
| Hedenius et al.130                         | Intermittent claudication                               | Non-RCT; 58 subjects; 5 groups                                                      | PSWT                                        | 975 65 600 38    | 372 (over 62 weeks); 20 min/session | Yes                                       | 14                                |
| Santoro et al.131                          | Arterial peripheral vascular disease                    | Doppler pressure, Laser Doppler Flowmetry, transcutaneous partial pressure of oxygen and thermistor thermography | Cohort; 10 subjects; 1 group                | PSWT            | NR 95 7000/700 NR | 20 (over 4 weeks); 30 (20 + 10) min/session | Yes                                       | 12                                |

Notes: RCT – Randomised controlled trial; ROM – Range of movement; RF – Radiofrequency; CSWT – Continuous shortwave therapy; PSWT – Pulsed shortwave therapy; PP – Peak power; PD – Pulse duration; PRR – Pulse repetition rate; MP – Mean power; NR – Not reported; NA – Not available to the authors; W – Watts; μs – Microseconds; pps – Pulses per second; min – Minutes.
a well-controlled double-blinded RCT by Seabone and colleagues.\textsuperscript{113} The study had four groups, each acting as its own control. All groups improved significantly, but no significant difference existed between the groups. The study, however, was low on statistical power.

Among the other studies, Sharp\textsuperscript{124} and Comorosan and colleagues\textsuperscript{40} reported accelerated bone repair with externally applied PSWT in 16 cases of non-union of fractures and 45 patients with post-traumatic algoneurodystrophies, respectively.

While the need for further quality research was evident, the existing studies indicated the potential usefulness of PSWT in facilitating the healing of pressure ulcers. The number of well-designed and adequately controlled studies on tissue healing was fairly low. The majority of studies did not report dosage parameters or the rationale for dose selection. Also, the durations of intervention varied greatly, making it difficult to draw any commonalities between the studies (Table 4).

**Studies on other applications**

While the majority of research centred on RF-based therapy for the reduction of pain and inflammation, and several others on tissue healing, a limited number of studies investigated conditions such as post-traumatic/post-surgical stiffness and ROM,\textsuperscript{125–129} and vascular disorders.\textsuperscript{130,131}

Results of some preliminary investigations on the therapeutic effect of PSWT on ‘intermittent claudication’ were published by Hedenius and colleagues in 1966.\textsuperscript{130}

In a multi-group study, 18 patients treated with PSWT (372 individual sessions in 62 weeks, 20 min per session) showed significantly improved skin temperature and walking tolerance over those who did not receive PSWT. Fair improvement in walking tolerance was also reported by Santoro and colleagues\textsuperscript{131} in a small cohort study of 10 participants suffering from peripheral vascular disease, when treated by CSWT (20 sessions in 4 weeks, 30 min per session).

Five case studies\textsuperscript{125–129} published by Draper and colleagues demonstrated the clinical effectiveness of PSWT for improving ankle joint ROM\textsuperscript{126} (8–13 sessions in 5 weeks, 20 min per session), elbow joint ROM\textsuperscript{125,129} (4–9 sessions in 2–3 weeks, 20 min per session) and symptoms of necrotising fasciitis\textsuperscript{128} (12–15 sessions in 6 weeks, 20 min per session to each body segment treated); and CSWT (daily sessions for 2 weeks, 20 min per session) for improving post-operative ROM in the knee joint.\textsuperscript{127} The RF treatment was combined with manual therapy and/or joint mobilisations in all cases. It is suggested that PSWT at thermal doses can be applied safely over areas with metal implants, if delivered with proper technique and caution.\textsuperscript{125}

High-dose treatments using 38–48 W of energy were employed in all these case studies with the duration of intervention lasting 2–6 weeks. The dose selection was aimed at delivering heat to the tissues, thereby raising the tissue temperature by up to 4 °C. Nonetheless, proper clinical trials with adequate control, sufficient sample and blinded methods need to be carried out before any conclusions can be drawn (Table 5).

**Conclusions**

Evidence favouring and against RF-based EPAs (between 30 kHz and 30 MHz) as a treatment modality for chronic therapy-related clinical conditions is available. The majority of the identified studies (91%) were SWT-based, and done on conditions giving rise to pain and inflammation, mainly OA knee and chronic LBP.

Although the review did not employ a cut-off score (Downs and Black) for the methodological quality, the conclusions drawn here are based primarily on the results reported by well-designed studies and the overall weightage of the available evidence. The authors could not determine a clear association between the quality scores achieved by the studies and their reported clinical outcome. While some studies that scored highly (>20) on the Downs and Black scale reported RF to be beneficial, some others reported them to be not beneficial. The same is true also for studies that scored low (<20) on the scale.

Many of the studies published in the earlier decades gave conflicting results on the efficacy of SWT for the management of OA. However, several well-designed and recently published studies have supported the use of SWT in the treatment of OA; mainly in its pulsed form (PSWT).

Hence, on the whole there is moderate evidence to support the use of PSWT in OA knee. Apart from OA knee, some evidence also exists favouring the use of CSWT to treat chronic LBP. Sufficient robust evidence does not exist for any other chronic conditions giving rise to pain and inflammation.

For OA knee, based on the available evidence the authors recommend that a mean PSWT power dose at or above 14.5 W, 8–12 sessions over 4–6 weeks and 15–20 min per session may be necessary for the treatment to be beneficial. No recommendations on CSWT dosing can be given for the treatment of LBP based on the available evidence, as the doses were not objectively reported adequately.

Some evidence also exists favouring the use of PSWT to promote the healing of chronic wounds, although the majority of studies identified in this category were case studies. While the need for more quality research was evident, the existing studies indicated the usefulness of PSWT in facilitating the healing of pressure ulcers. Although low in number, all reported clinical trials in this category were reasonably well-designed and favoured the use of PSWT for treating pressure ulcers. However, similar to LBP, no recommendations on dosing can be given since the dosage parameters were rarely reported and the durations of intervention varied greatly among the studies.

Since the bulk of the literature centred on applications pertaining to the reduction of pain and inflammation and...
several others to tissue healing, only a limited number of studies investigated the effects of RF-based therapy on other conditions such as tissue extensibility and ROM. All the identified studies in this area were case studies, and all of them indicated that PSWT may be potentially beneficial for improving ROM in the management of conditions such as post-traumatic stiffness. Nonetheless, proper clinical trials with adequate control, sufficient sample and blinded methods need to be carried out before any recommendations can be made.

Only a limited number of clinical studies have been published in the non-shortwave RF frequency range on chronic conditions. Purely on the basis of the results reported, 448 kHZ RF might be beneficial in delivering useful therapeutic effects. However, the paucity of clinical studies and their poor methodological quality suggest there is a need for more research in this area before such therapy can be recommended.

The evidence reported in this review may only be considered against the overall quality of the studies, which was generally lacking. This is somewhat similar to the findings of part I19 of this review. Lack of robustness and integrity in the methodological designs and poor overall reporting (including the reporting of dosage parameters) made the assessment of results problematic for most studies. Where doses were reported, the rationale for selection was unclear. Many trials also had flaws in their study grouping and did not demonstrate sufficient statistical equivalence between the groups at baseline, where comparisons were made between groups. Several studies either did not have adequate statistical power or failed to report any information relating to statistical power. Furthermore, participant dropouts were sometimes high, but were not accounted for in the final analysis (no intention-to-treat analysis) as would be expected in a more recent publication. The lack of consistency in reporting and poor methodological quality was particularly evident in the earlier studies. Although both criteria were increasingly met in the more recent studies, proper reporting of the dosage parameters continued to be an issue.

Despite the fact that RF-based EPAs have been used in therapy practice for almost a century, research in this area remains limited. Both the number of studies published on their effects on chronic conditions, and the types of conditions researched are limited. This warrants substantially more research in this area. Nonetheless, the overall numbers are greater than that was identified on the acute conditions in part I.19 A lack of research emphasis is particularly evident on the non-shortwave RF band, where only a very small number of studies were identified. This warrants particular emphasis in this area especially since EPAs delivering non-shortwave RF are already in clinical use and that the studies published so far have reported encouraging results.

Notes on Contributors
This paper is an excerpt from the Doctoral research of the first author (BK). The second author (TW) is a prominent academic, author and professor in Physiotherapy at the University of Hertfordshire. The first author is responsible for the research involved and writing-up of this manuscript. The second author is responsible for the guidance on research and writing-up, and the overall supervision of this research work.

Conflict of interest
The University of Hertfordshire is in receipt of an industry linked research funding related to this programme of research (Indiba S. A., Barcelona, Spain). The industry funders had no role in the conduct of this study or the preparation of this manuscript. The authors alone are responsible for the content and writing of the paper.

Ethics approval
Not applicable.

Disclosure statements
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