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Corresponding Author: Mr Leon Poltawski,

Corresponding Author's Institution: University of Hertfordshire

First Author: Leon Poltawski

Order of Authors: Leon Poltawski; Tim Watson

Abstract: Microcurrent therapy is unique amongst the electrophysical modalities in applying electric fields and currents of similar form and magnitude to those produced naturally by the body. The therapy involves application of electric currents of the order of millionths of an amp, and there is evidence that it can promote healing in a variety of damaged tissues. Clinical trial evidence indicates that the therapy may be effective with non-uniting fractures, spinal fusions and a skin ulcers of varying aetiology, particularly where other forms of treatment have not been successful. In vitro, animal and human studies also suggest that there is unexplored potential for the application of microcurrent to a variety of musculoskeletal disorders. However, higher quality and more comprehensive clinical trial data may be required before musculoskeletal clinicians consider adding this modality to their electrotherapy repertoire.

***Title page**

BIOELECTRICITY AND MICROCURRENT THERAPY FOR TISSUE HEALING – A NARRATIVE REVIEW

Leon Poltawski
School of Health & Emergency Professions, University of Hertfordshire, Hatfield, AL10 9AB, UK.
Tel +44 1707 284968. Email: L.Poltawski@herts.ac.uk (Corresponding author)

Tim Watson
School of Health & Emergency Professions, University of Hertfordshire, Hatfield, AL10 9AB, UK

ABSTRACT

Microcurrent therapy is unique amongst the electrophysical modalities in applying electric fields and currents of similar form and magnitude to those produced naturally by the body. The therapy involves application of electric currents of the order of millionths of an amp, and there is evidence that it can promote healing in a variety of damaged tissues. Clinical trial evidence indicates that the therapy may be effective with non-uniting fractures, spinal fusions and a skin ulcers of varying aetiology, particularly where other forms of treatment have not been successful. In vitro, animal and human studies also suggest that there is unexplored potential for the application of microcurrent to a variety of musculoskeletal disorders. However, higher quality and more comprehensive clinical trial data may be required before musculoskeletal clinicians consider adding this modality to their electrotherapy repertoire.

KEYWORDS

Bioelectricity, Electrotherapy, Microcurrent, Tissue Healing

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INTRODUCTION

Contemporary accounts of tissue healing are typically expressed entirely in terms of biochemistry[1-4]. The actions of substances such as cytokines and growth factors are said to initiate and mediate the various stages of inflammation and repair that normally follow tissue damage[5]. Yet evidence has accumulated over many decades that a full description of the physiology of healing must also include the role of bioelectricity, accumulations and flows of charge that are generated endogenously - within the body. The importance of bioelectricity in functions such as nervous system signalling and muscle contraction has been long recognised, but it is involved in many other physiological processes. These include the development, adaptation, repair and regeneration of tissues throughout the body[6-9].

Recognition of bioelectricity's role in tissue healing provides a rationale for the therapeutic application of electrical stimulation, particularly in cases where natural repair processes have broken down. Microcurrent therapy (MCT) is an example of this. Uniquely amongst the various electrotherapeutic modalities, MCT involves application of voltages and currents of similar magnitude to those generated endogenously during normal tissue healing. Although relatively unknown and currently little used by physiotherapists, MCT has been shown to be of benefit in several types of tissue healing and it may be effective in others. It has advantages of stimulating healing generally, and not just one element of the process; it has very few side effects; and it may offer an effective treatment for musculoskeletal disorders such as tendinopathies where endogenous healing appears to be dysfunctional.

This paper outlines current thinking on the role of bioelectricity in healing, presents empirical evidence regarding MCT for the promotion of tissue healing, and suggests implications for both clinical and research communities. The majority of published research in this area is concerned with bone and skin lesions, but patterns and mechanisms of healing in these tissues share features with those seen in damaged tendons, ligaments and other musculoskeletal structures[10-12]. Therefore the evidence presented here is of relevance to researchers and clinicians concerned with a variety of musculoskeletal disorders.

Bioelectricity and healing

The human body, in common with other living organisms, expends a significant proportion of its energy generating electricity[13]. In fact the body is a conglomeration of electric batteries. Every cell maintains a voltage across its external membrane, and across the membranes of its organelles[14, 15]. This is achieved by the active transport of ions, particularly sodium (Na^+) and Potassium (K^+), against their concentration gradients, establishing charge separations that constitute a potential difference or voltage across the membrane[16]. Aggregates of cells also set up voltages across various tissue layers, cutaneous and corneal epithelium, vascular and intestinal walls, and the cortex and periosteum of long bones[14, 15, 17-21]. These voltages are of the order of millvolts (mV) in magnitude, and where there is a conducting pathway they cause the movement of ions within tissue, constituting a bioelectric current, typically in the microamp (μA) range[14].

At the cellular level, bioelectricity is involved in the transport through the membrane of ions that can mediate cell behaviour. Even in non-excitable cells there are voltage-gated channels controlling the passage of ions that mediate cell behaviour[22]. At the tissue level, endogenous fields are intrinsic to a number of metabolic processes, including development, adaptation and repair. They can influence cell morphology and the growth of body parts during foetal development[13, 23, 24]; they are generated when connective tissues such as bone and tendon are stressed and can influence adaptive modifications in the extracellular matrix[25-28]; and when tissue is damaged they set up currents that appear to drive elements of the healing response[17, 29-32]. The currents diminish as healing progresses, with normal values being re-established once healing is complete [17, 23, 32, 33].

That bioelectricity is intrinsic to such processes – rather than mere by-products – has been established by a wealth of experimental evidence. Perhaps the most convincing is that setting up a voltage in opposition to the endogenous one, or blocking the passage of biocurrents in wounds, can slow or abolish the healing response in a variety of tissue types [15, 33-35]. In vitro studies have also demonstrated that application of electric fields and currents similar to those generated within the body can cause significant changes in the structure and behaviour of cells. Application of microcurrent to tissue has been found to boost the number of organelles responsible for cellular activities, and to increase concentrations of ATP, the cellular currency of energy[36, 37]. These changes can facilitate cell proliferation and protein synthesis, which have been found to increase when microcurrents are applied to the constituent cells of skin[38, 39], tendons[40, 41], cartilage[42] and bone[43]. Such effects are highly parameter-dependent, however. Larger currents or alternating microcurrents at certain frequencies have been found to reduce cell proliferation or induce cell death in some cases[44, 45].

Ion channels in cell membranes may migrate under the influence of an applied field, resulting in cytoskeletal modifications, including creation of membrane projections that cause cell movement[24, 37]. Directed movement of cells within an electric field – known as galvanotaxis – has been observed with many cell types. These include leukocytes and macrophages, which are key mediators in different stages of healing[46], as well as a variety of cells responsible for tissue formation, such as keratinocytes, vascular endothelial cells, osteoblasts, osteoclasts, chondrocytes and fibroblasts [24, 37, 47, 48]. Different cell types have been found to move in opposite directions, and reversing the field reverses the direction of migration[37, 49].

At the tissue level, unidirectional fields and direct currents (DC) can promote vascular permeability[50] angiogenesis[51] and neural sprouting[31, 52] as well as formation of new skin, bone, cartilage and soft tissue formation [39, 53-57]. Such findings are significant because they suggest that applying fields and currents with similar parameters to bioelectricity may be used to stimulate tissue healing. Cell migration, proliferation and synthesis of new tissue are all essential components of the healing process [1, 46]. If applied electricity can mimic endogenous electrical signals that guide cellular behaviour, then a therapeutic option may be available where natural healing has failed.

Therapeutic Microcurrent

There are various forms of electrotherapy that may deliver average currents in the microamp range, such as high voltage pulsed current (HVPC) and high frequency alternating currents induced by electric or electromagnetic fields (e.g. Pulsed Short-wave Therapy). However, the waveforms produced by these modalities are quite unlike those of any observed endogenous currents and voltages, which tend to be unidirectional, and of constant or slowly varying amplitude[14]. Since MCT is predicated on the basis that it mimics endogenous bioelectric signals, the main focus here is on those studies that use electrical stimulation with similar parameters. A good deal of evidence regarding the effects of microcurrent on tissue healing has accumulated over recent decades. Where clinical trials have been reported, they are presented, though reference to in vitro and animal studies is also made where clinical trial data is scarce.

BONE

Electrical stimulation was used for promotion of bone healing in the early 19th century. English physician John Birch applied direct current to the ends of a 13 month-old non-uniting tibial fracture via percutaneous electrodes[58]. After 6 weeks of treatment the fracture had consolidated. Other historical examples of electricity being used in this way era are recorded, but the therapy later fell into disuse. It was revived in the mid 20th century, when a scientific rationale for its application was developed on the basis of in vitro and animal experiments. In the 1950s several workers found that application of microcurrent to bone could initiate osteogenesis in both normal and damaged bone [59, 60]. Later studies investigated the effects of parameters such as current size, polarity and electrode material and configuration on the process [61-63]. New bone could be laid down by direct currents of about 20 μA, with maximal formation occurring at the cathode (the negative electrode). Currents above 30 μA could cause bone resorption or osteonecrosis [55, 62, 64]. Such data provide a convincing rationale for the use of microcurrent to stimulated bone healing, and subsequent in vivo animal studies suggested that it might be beneficial for several clinical applications, including fresh fractures, delayed and non-uniting fractures, osteotomies and spinal fusions, although parameter choices varied considerably and not all applications were successful [65-70]. For reviews of such studies, see [71, 72].

Clinical studies

The earliest modern application of MCT for human bone healing was to non-uniting fractures. In 1971, Friedenberg and colleagues published a case study in which a malleolar fracture, which had failed to unite after more than a year, was healed by treatment with direct current of 10 μA via a cathode inserted into the fracture site[73]. Several larger studies followed, in which MCT was applied to delayed or non-uniting fractures. Delayed unions are those that take longer than would be expected for the particular fracture site and patient characteristics; non-union is said to occur when healing stops and union is not achieved after 6 – 8 months[74]. In 1977 Brighton and colleagues reported a study involving treatment of 57 lower and upper limb non-unions with 10 - 20 μA, delivered to the site by 2 - 4 cathodes for 12 weeks, followed by 12 weeks further immobilisation[75]. Of those treated, 76% went on to develop full union, with most failures accounted for by insufficient current delivery or breakage of electrodes. In a follow-up multi-centre study 84% of 178 non-unions treated using a similar protocol achieved union. Complications were reported as minor[76]. Another multicentre trial in a different country used the same current but delivered through a single cathode to 84 patients with either delayed or non-union[77], mostly of the tibia or femur. Time to achieve union varied between 12 and 36 weeks. A ten-year follow-up assessment of 37 of the patients enrolled in this trial found normal bone remodelling, continued union and no side effects of the electrodes that were left in situ (the remaining participants were unavailable for review)[78].

Microcurrent pulsed at 20 Hz has also been evaluated and found beneficial with a mixed caseload of non-uniting fractures, congenital pseudarthroses, osteotomies and leg-lengthening procedures. DC of pulse amplitude 20 – 25 μA and duration 30 ms was applied via a cathode wrapped around or threaded through the fracture site and with the anode implanted in the medulla (as opposed to the subcutaneous positioning used in other trials). Treatment times varied according to case until union was observed radiographically, and varied between 2 and 12 months. The overall success rate was 87% although adjunctive treatments and individual characteristics varied considerably. Authors of one of the earlier studies[75] reported that they found that constant DC always produced superior outcomes to pulsed current, although they presented no relevant parameter or outcome data.

Some of these studies are rather dated and do not meet contemporary reporting standards for clinical trials. The absence of a formal control group is justified by the fact that usually no bone healing had been observed for months, and spontaneous recovery in such cases is rare, so participants were considered to be acting as their own controls[76]. However placebo and time effects cannot be ruled out when evaluating their evidence. The lack of more recent studies may reflect the greater popularity of less invasive electrotherapeutic modalities[79], although MCT may give superior results in selected cases. A comparison with capacitative and inductive coupling as adjuncts for bone graft treatment of tibial non-unions reported in 1995 found that microcurrent was more effective with high risk cases such as those with atrophic non-unions or previous graft failure[80]. Where there were no identified risk factors, none of the electrotherapies was superior to graft alone.

Although non-invasive forms of electrotherapy have superseded MCT for some applications, it has continued to be employed in selected cases of lumbar spinal fusions, where there is evidence of its superiority over other modalities. Lumbar spinal fusions are used in cases of disabling joint instability or disc degeneration, and normally involve a bone graft and instrumentation. Failure rates can be as high as 40%[81], but may be reduced substantially by the application of MCT. After its first clinical use was reported in 1974[82], direct current application, typically of 20 μA applied by a single or multiple cathodes to the fusion site for 5-6 months, was subject to evaluation in several trials[83-85]. In these studies patients receiving MCT in addition to standard treatment had successful fusion rates of 81 – 96%, compared to 54 – 81% for those on standard treatment alone, as assessed by radiographic and clinical criteria. Results for methodologically sound controlled trials consistently indicate statistically significant outcomes in favour of DC MCT compared with control groups[86]. It is particularly effective when used in high risk cases such as those with previous failed fusions, multiple level surgery, smokers and those with co-morbidities such as diabetes and obesity[87-89], and has a stronger evidence base in its favour than either CC or IC, particularly for posterior fusions[90]. An economic evaluation of the therapy as an adjunct in spinal fusion surgery[91] also found that it provided significant cost savings and shorter in-patient stays.

Other small studies have suggested that DC MCT may be useful in other bone lesions, including high risk ankle and hind-foot fusions[92, 93] and selected congenital pseudarthoses[94-97]. Their findings have yet to be confirmed in larger trials. Two controlled trials have suggested that MCT may also accelerate healing in fresh fractures[98, 99], though this application is still largely unexplored.

Systematic reviews of trials have concluded that the best evidence for promotion of bone healing by application of small electric currents is in cases of non-uniting lower limb fractures and spinal fusions[71, 86, 88, 90, 100-105]. Meta-analyses have been weakened by pooling data from trials using heterogeneous groups and treatment parameters, and even different forms of electrotherapy [86, 101]. Nevertheless, consideration of the evidence regarding MCT in particular suggests that its application, usually for several months, may enhance tissue healing in a variety of bone lesions.

SKIN

Since it is easily accessible for study, skin is the tissue in which the bioelectrics of healing have perhaps been subject to the greatest scrutiny. Several reviews providing accounts of in vitro and animal studies are available[53, 72, 106], and only the human and clinical studies are dealt with here. Several authors have identified the seventeenth century use of charged gold leaf for resolution of smallpox lesions as the first example of electrotherapy for human skin healing[53, 107, 108]. In fact there is no mention of electric charge in the cited source[109]. Charged gold leaf, which would deliver small and diminishing currents to adjacent tissue, was used successfully in the 1960s to assist healing in surgical vascular wounds and cutaneous ulcers[110, 111]. However, charging appears to have been considered an aid to adherence of the leaf rather than an agent of healing in itself. Nevertheless, more recent studies have consistently concluded that electrical stimulation, including MCT, can indeed promote healing in various types of human skin wounds, particularly ulcers. The first of these was reported in 1968 by Assimacopoulos who, following successful use of microcurrent to accelerate healing of surgical scars on rabbit ears[112], tried the treatment with recalcitrant leg ulcers in three patients[113]. Direct current between 50 and 100 μA was delivered continuously for several weeks via a stainless steel mesh cathode soaked in saline and placed on a moist dressing on the wound, and an anode affixed to the thigh or abdominal wall. All the wounds healed within 6 weeks ands no side effects of treatment were reported.

In a larger study, Wolcott and colleagues used MCT with 83 ulcers of varying aetiology in 67 patients[114]. A measure of control was introduced by assessing but not treating additional ulcers in eight of the sample patients. “About three quarters” of the patients had failed to respond to other conservative treatment. Direct current between 400 and 800 μA was applied via a copper mesh cathode over the wound and anode on skin 15cm proximal. The current level was determined individually, adjusted so as to avoid bleeding or excess exudate production, and was delivered for 2 hours, thrice daily for several weeks, is some cases months, until healing occurred (a full breakdown of durations was not given). The protocol involved a polarity-swapping element, based on early experience that healing would often plateau after a few days and could be restarted by reversing the polarity of the electrodes. Over a mean treatment time of 7.7 weeks, there was a mean volume reduction in treated wounds of 82%, with a mean healing rate of 13.4% per week. 34 lesions (40%) healed completely. These figures mask a wide range of individual and group responses, with paraplegic patients (presumably mostly spinal cord injured) consistently responding less well to treatment. Of the eight patients (mostly paraplegic) with microcurrent-treated and control ulcers, mean volume reductions were 93 (range 75 – 100) % in the MCT ulcers and 33 (range 0 – 75) % in the control ulcers. The study evidence is weakened by the lack of information on duration of ulcers, the inclusion of patients for whom standard treatments had not been tried, early termination of electrotherapy protocol in more than half of the sample, and the small size of the control group. Even so, it began to build the case that MCT could assist healing in a variety of skin ulcer types.

MCT using similar protocols – and various alternatives - were later used in several larger controlled trials by other groups[115-121]. These involved a variety of skin ulcer types including those due to venous and arterial insufficiency, secondary to diabetes, and pressure ulcers following spinal cord injury. MCT typically involved currents of the order of several hundred microamps, often continuous DC but sometimes pulsed or low frequency biphasic. Where currents were unidirectional, the anode was normally placed on the wound, within a moist dressing. Treatment times were usually an hour or more each day for several weeks or even months. Healing was measured in terms of percentage reductions in wound surface area or volume over a defined time, and in the majority of cases ulcers receiving MCT as an adjunct to conventional treatment healed more quickly and completely than those receiving conventional treatment alone.

More recent studies have suggested that MCT may also be effective with other types of skin wounds. In a trial involving 30 patients, microcurrent of was found more effective than conventional treatment in promoting skin graft healing following thermal injury[122]. A DC current between 50 and 100 μA was applied continuously

for several days via an anodal dressing on the wound. Stimulated wounds closed in an average 4.6 days compared to 7.2 days for controls. A series of case studies involving application of monophasic microcurrent to pressure sores, an infected venous ulcer and a recalcitrant pilonidal sinus also found evidence of benefit in terms of [123] accelerated healing and reduction of bacterial load. The novelty of these cases was that the current (of unspecified magnitude) was provided by a proprietary dressing with an integrated circuit and battery and electrodes.

Reviews of electrical stimulation for skin wound healing have consistently concluded that the weight of evidence is in its favour when it is used as adjunctive treatment with other conservative management strategies [53, 86, 108, 124-128]. In the USA, government and private medical insurers pay for its use with recalcitrant ulcers due to pressure, arterial or venous insufficiency and diabetes [127]. However most reviews have not considered the different modalities separately, because the numbers would not justify subgroup analysis. Where MCT studies are considered alone, the range of protocols employed means that optimum parameters cannot yet be identified. Both continuous and pulsed, monophasic and biphasic, anodal and cathodal stimulation seem capable of promoting healing. The parameters that are supported by a majority of studies are current size (in the hundreds of microamps), treatment time (typically several weeks, for hours rather than minutes each day) and application directly to the wound bed. Monophasic or “unbalanced” currents (those with a net delivery of charge) are more common in the studies indicating MCT effectiveness.

TENDONS AND OTHER TISSUES

Data from in vitro and animal studies, and a small number of human trials, suggest that there may be unexplored potential for microcurrent treatment of soft connective tissue lesions, particularly in tendons and ligaments. In these structures, the extracellular matrix (ECM) is laid down by various phenotypes of the fibroblast, a cell that has been shown to migrate, proliferate and increase synthesis of ECM proteins under the influence of applied electric fields and currents[40, 41, 129-132].

Tissue and animal studies

By using explants, whole tissue samples taken from animals and maintained in laboratory cultures, investigators have been able to conduct well-controlled studies of the effects of applied current on tendons and ligaments. Nessler and Mass reported using these methods in 1987, when they applied continuous 7 μA current for up to 6 weeks to surgically transected and sutured rabbit flexor tendon explants[133]. Bioassay and histological analysis showed greater and more rapid fibroblast proliferation, protein synthesis and collagen deposition consistent with normal tendon healing in stimulated explants compared to their controls. These changes were observed distant from the cathode, which had been placed into the lesion, and the authors speculated that the current density was too great close to the cathode. Soon after, Cleary and colleagues investigated the influence of various microcurrent parameters by applying pulsed monophasic microcurrent to chicken flexor tendon explants for three days, varying current amplitude, direction and pulsing frequency[130]. They found that levels of fibroblast proliferation, protein synthesis and collagen fibroplasia at the cut surfaces of stimulated explants were significantly greater than those of unstimulated controls. Effect sizes were greatest at current densities of near 1 $\mu A/cm^2$, and at pulse frequency 1 Hz, and dropped off at higher values. Applying the current longitudinally maximised the effects, whilst no significant differences between treated and control explants were found with transverse application. This observation was explained by other studies showing that fibroblasts lay down collagen fibres parallel to the direction of the applied field[134, 135].

In a study using explants of rabbit flexor tendons and their sheaths, longitudinal stimulation with various DC microcurrent levels was applied for up to 2 weeks[41]. Investigation of the cut surfaces revealed evidence of cell proliferation and collagen deposition in both treated and control samples, with adhesions forming in the

epitenon-sheath as a result. Application of microcurrent caused different effects according to current size. Above 1 μA there was evidence of tissue degeneration and cell death, but at 0.5 μA proliferation continued in the tendon substance but was significantly reduced in the sheath. This observation rather astonishingly suggests that microcurrent can selectively inhibit proliferation that would lead to counterproductive adhesion formation during sheathed-tendon healing.

In the first reported in vivo animal study, low level current was applied to surgically wounded flexor tendons of 6 ponies via a cathode implanted in the wound and an anode 3cm distal[136]. No gross or histological differences were seen between treated and contralateral control tendons at 4, 5 and 6 weeks post-injury. The author speculated that the (unmonitored) current, provided by a bimetallic strip, may have been too low to affect healing. Later studies were more encouraging, though a wide range of parameters was adopted, making generalisation from their results problematic. Stanish and colleagues transected the medial portion of the patellar tendons of nine dogs and divided them into three groups, receiving plaster immobilisation, brief compression bandaging or constant 20 μA current applied via a cathode wrapped around the tendon[137]. After six weeks the dogs were killed and the tendons removed with their contralateral counterparts for comparison. Breaking strengths as a percentage of the normal tendon values were 47% and 50% for the first two groups, and 92% for the MCT group. Though the sample sizes were small, the difference is striking.

In a larger study[138], the patellar tendons of 45 rabbits were transected bilaterally and cathodes sutured into the lesions, anodes mounted on the tissue surface. One limb was left untreated, the other given 10 μA DC continuously, with tendons removed at for three, five or seven weeks for evaluation. Mechanical strength was found to increase more rapidly in the early weeks in stimulated tendons, whilst mature collagen formation was greater in the later weeks, compared to controls. This suggested that MCT could accelerate healing in both proliferative and remodelling phases of healing.

Subsequent studies with rat Achilles tendons, knee ligaments and joint capsules have consistently suggested that MCT with a range of parameters can accelerate repair and result in stronger tissue and reduced contracture formation after injury, compared to unstimulated controls[56, 139-143]. Microcurrent has also been observed to promote rabbit cartilage growth[57] and repair[144], as well as rat peripheral nerve regeneration[52]. DC or unbalanced biphasic current was used in all the tendon studies, but AC was also successfully employed with other tissues. Treatment times varied between one and 24 hours a day for between one and four weeks. Where currents were modulated, their amplitudes were of the order of 100 μA (with considerably lower average values), and electrodes were implanted, usually delivering current parallel to fibre orientation. The strength of the studies is in their use of contralateral controls, allowing a cause-effect relationship to be established. However their findings cannot be aggregated because of heterogeneity in their treatment parameters. They all used surgical means to create lesions and animal models that are imperfect analogues of human tissue disorders. The lack of histological data also means that conclusions cannot be drawn about repair processes. Despite these limitations, they provide evidence that microcurrent can promote resolution of tissue damage, and have justified progression to clinical trials of MCT.

Human studies

Following their work with surgically wounded canine tendons, Stanish and colleagues reported on a series of more than 100 patients in which MCT was used after surgical repair of torn Achilles and patellar tendons and anterior cruciate ligaments. A direct current of 20 μA was applied (for an unreported time, presumably several weeks) via a cathode wrapped around the lesion and a subcutaneous anode and power-pack. The authors reported accelerated return to full weight-bearing and function, and histological analysis of 45 reconstructed ligaments 9 months after surgery showed the tissue to be revascularised with mature and well organised collagen. This was not a formally controlled trial, however, and little numerical data is provided for scrutiny.

MCT has been subject to trial with several examples of chronic tendinopathy. One involved 48 people with Achilles tendinopathy of at least 3 months system duration, randomly assigned to receive either microcurrent or conventional conservative treatment[145]. A monophasic square wave of amplitude 40 μA and frequency 10Hz was applied via surface electrodes placed transversely across the lesion. Treatment was for 30 minutes daily over 14 days, followed by a regime of eccentric exercises. Numerical measures of patient-rated pain and stiffness and clinician-rated clinical status were recorded at baseline and at 3, 6 and 12 months after treatment. Statistically significant differences in favour of the MCT group were found in these measures. Sonography, which can be used to image changes associated with tendinopathy[146, 147], was also employed. The authors reported that sonographic findings were "in agreement" with these outcomes, though specific data are not given. Improvements were most marked in the first three months after treatment. The study is weakened by non-standardisation of the conventional treatment and a complex and unvalidated scoring system used with the outcome measures. However, the data are encouraging.

A more recent pilot controlled trial has used MCT for chronic tennis elbow[148]. Sixteen people with symptoms lasting at least 3 months were randomly assigned to receive either a 6-week standardised exercise programme or exercise plus MCT. Biphasic square wave current with a variety of parameters including amplitudes 40 μA or 300 μA and frequencies of 0.3, 3 and 30 Hz. Treatment was administered via probes contacting the skin at various points on the elbow and forearm for several minutes, ten times over three weeks. Outcome measures were pressure pain threshold at the tendon, grip strength and pain on gripping, recorded at baseline and 1, 2, 3 and 6 weeks later. All participants improved but no significant differences between groups were seen in any of the outcome measures. The conclusions may have been affected by the small sample size of the study, but in any case it was hampered at the outset by the use of MCT with very short duration and methods of application that were given no scientific justification by the authors.

Trials using microcurrent have been reported for a range of other soft tissue lesions, including plantar fasciitis[149], delayed-onset muscle soreness (DOMS)[150-152], radiation-induced fibrosis[153] and osteoarthritis[154]. The outcomes of these trials suggest – though not unequivocally - the MCT may have an analgesic effect that is not due to sensory stimulation, since the treatment is normally sub-sensory. Pain relief may account for the improvement in other outcome measures such as range of movement and function. In one study there was also evidence of mediation of the healing process. Serum creatine kinase (CK) levels, which elevate following muscle damage, were found to be lower in DOMS-induced muscles after MCT than in an untreated control group. The microcurrent was delivered by a skin-mounted charged dielectric pad, providing an average 20μA over 48 hours, and the CK level differences were significantly lower in the treated group 4-7 days after injury [151].

Drawing firm conclusions from these human studies is hampered by various factors. In particular, the use of proprietary devices delivering microcurrent whose parameters are based on little if any scientific rationale. The outcome measured they adopt often give only indirect information about tissue status, and some studies are poorly constructed or reported. Nevertheless they suggest that MCT may have potential in promoting the resolution of various musculoskeletal soft tissue disorders, and indicate the need for well-conducted clinical trials. The normally sub-sensory nature of microcurrent means that double-blind placebo-controlled trials, which could provide convincing evidence, are practicable. However, at least for the present, the most robust evidence in favour of MCT for soft tissue lesions is provided by cellular and animal studies.

CONCLUSIONS

The evidence in support of MCT has been convincing enough to justify its inclusion in the clinician's repertoire for treatment of several examples of recalcitrant bone and skin lesions. Indeed federal and private health

insurance providers in the USA have accepted its use (along with other forms of electrical stimulation) for spinal fusions and hard to heal skin ulcers for some years[53, 83]. In contrast, the lack of substantial and robust human trial evidence for the use of MCT with musculoskeletal soft tissue lesions is frustrating. Clinicians are justifiably cautious when presented with yet another form of electrotherapy, especially when the case for more familiar and well-used modalities such as therapeutic ultrasound has been questioned in several reviews[155-157].

Yet MCT has several significant features in its favour: there is already substantial evidence that it can promote healing in a variety of tissue types and disorders, especially where other approaches have failed; it may help redress an underlying physiological dysfunction as well as reducing its symptoms; its mechanism of action appears to be as a trigger or facilitator of the healing process, unlike some new approaches such as exogenous growth factors, which have specific targets in the healing cascade. Reported side-effects of MCT are few and minor, and it can be provided by a small, portable generator, over an extended period where necessary, requiring minimal therapist supervision once initiated. The therapy has been shown to be most beneficial when it is used as part of a broader management strategy. Given these characteristics, the potential for MCT in a range of recalcitrant musculoskeletal disorders is worthy of closer attention by both research and clinical communities.

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